National Park Service
U.S. Department of the Interior

Mammoth Cave National Park

Mammoth Cave National Park
Fire Management Plan
December 2001


Fireline Handbook
FIRE SHELTER
USE INSTRUCTIONS
FSS

Mammoth Cave National Park
Fire Management Plan
December 2001

Mammoth Cave National Park
Mammoth Cave, Kentucky

Produced by the Office of the Superintendent
Mammoth Cave National Park
U.S. Department of the Interior

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Appendices 1 and 2 are included in this document. The others are available for viewing at the park.

Acknowledgements

Development of this plan has involved every division in the park, and will continue to need park-wide participation. We are gateful to Superintendent Switzer for supporting this plan to safely restore fire as an ecological process. To those who went before us and provided excellent Fire Management Plan examples to follow, we have a great appreciation for what you accomplished. The plans for Great Smoky Mountains National Park (Leon Konz), Natchez Trace Parkway (Dan Mapstone), Kings Mountain National Military Park (Dr. Carlisle Franklin, North Carolina State), Big South Fork National River and Recreation Area (Carl Douhan), and Colorado National Monument (NPS team effort) were especially helpful. As well, we thank the reviewers for their constructive criticism/guidance, and a special thanks to SERO Fire Ecologist Caroline Lansing for assistance with fire behavior modeling. Both the Kentucky and Missouri Chapters of The Nature Conservancy provided useful information on local and regional fire history and ecology. They have been and will continue to be important partners. Given the degree to which this plan relies upon Geographic Information Systems technology, we are thankful for the efforts of Michael Franz and Guy Perry. A more expansive list of people and organizations is listed in Section 18.

This plan began as part of a discussion between botanist Randy Seymour and Science & Resources Management Chief Jeff Bradybaugh about five years ago. (Deputy Superintendent Mick Holm seemed to be the only one who knew that it would take this long.) We are grateful to Mr. Seymour for his encouragement, educational programs, and vegetation management efforts in the park.

1.0 Introduction

1.1 Reasons for Developing the Plan

National Park Service (NPS) policy states that all national park units with vegetation capable of supporting fire will develop fire management plans (FMP). As well, this action is consistent with the mission statement and goals in the park Strategic Plan. The resource management plan (RMP) for Mammoth Cave National Park emphasizes restoration of fire as a natural ecological process. Study of pre-settlement fire history, and delineation of park sections that were probably influenced by fire are listed as top priority objectives upon which to base the FMP. Integral to this ecological restoration via implementation of the FMP is ensuring the protection and safety of people and property. The organizational structure of this FMP closely follows the Wildland Fire Management Reference Manual-18, which was issued in February of 1999.

1.2 NEPA and NHPA Compliance

This plan meets National Environmental Policy Act and National Historic Preservation Act requirements. As required by policy, an Environmental Assessment has been completed. This resulted in a Finding of No Significant Impact (see Appendix 1). The plan complies with Section 106 of the National Historic Preservation Act of 1966, Section 7 of the Endangered Species Act (as amended in 1973), and other related legislative and administrative requirements.

1.3 Authorities for Implementation

The authority for fire management is found in the National Park Service Organic Act (Act of August 25, 1916), which states that the National Park Service's purpose: "...is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Furthermore, the National Parks and Recreation Act of 1978 states: "Congress declares that...these areas, though distinct in character, are united into one national park system.... The authorization of activities shall be construed and the protection, management and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may be directly and specifically provided by Congress."

2.1 NPS Management Policies

2.0 Compliance with NPS Policy and Relation to Other Plans

National Park Service Management Policies (1988) state that "Park fire management programs will be designed around resource management objectives and the various zones of the park. Fire related management objectives will be clearly stated in a fire management plan, which is to be prepared for each park with vegetation capable of burning, to guide a fire management program that is responsive to park needs". "All fires will be monitored with sufficient instrumentation and documentation to (1) record the significant fire behavior and decisions, (2) determine whether specified objectives were met, and (3) assess fire effects. Agreements will be pursued at all levels to facilitate efficient fire management activities within and adjacent to parks." "The methods used to suppress all wildfires should be those minimizing the impact of the suppression action and the fire itself, commensurate with effective control. The full range of suppression strategies, from confinement through containment to full aggressive control will be considered by superintendents guiding suppression efforts."

2.2 Enabling Legislation of Mammoth Cave National Park

In an April 8, 1926 letter to Secretary of the Interior Hubert Work, the Southern Appalachian National Park Commission argued persuasively for the Secretary to endorse creation of Mammoth Cave National Park. The following month, on May 25, 1926 the President approved H.R. 13694, which provided for the establishment of the park. Key points the Commission made included 1) "Mammoth Cave is the best known and probably the largest of a remarkable group of caverns.", 2) "Another geological feature of much interest is found in the thousands of curious sink holes of varying sizes through which much of the drainage is carried to underground streams, there being few surface brooks or creeks", and 3) "The Mammoth Cave area is situated in one of the most rugged portions of the Mississippi Valley and contains areas of apparently original forests which, though comparatively small in extent, are of prime value from an ecological and scientific standpoint and should be preserved for all time in its virgin state for study and enjoyment."

In so doing, the Commission described the elements of the karst landscape in and around Mammoth Cave. They also made the case for scientifically based management as a means to maintain the natural processes required for both research and recreation. Suppression of fire has resulted in a loss of the desired "virgin state," and this FMP is an ecological restoration project designed to reverse that trend.

2.3 General Management Plan Objectives

The General Management Plan (GMP) sets as the goal for natural resources management: "To ensure long term perpetuation of the cave system, vegetation, wildlife, and other natural resources, and the processes that sustain them, free to the extent possible from the influence of human activities." Objectives to meet this goal are to: 1) promote in undeveloped lands the reestablishment of natural conditions and processes in areas previously disturbed by modern human uses (prehistoric Native American burning is considered natural by many fire ecologists), 2) initiate research to obtain the information necessary for management, interpretation, and use of park resources and the perpetuation of the cave system, 3) preserve unique surface features, archaeological sites, and lesser used caves pending the acquisition of scientific knowledge that will define acceptable parameters of use and preservation, and 4) protect and maintain a stable and healthy surface wildlife population through appropriate monitoring and control techniques as necessary to ensure a balanced ecosystem.

Additionally, the GMP states: "The aim of management at Mammoth Cave National Park is to perpetuate the integrity and diversity of geologic features and life systems that are associated with the caves, and the aquatic and terrestrial environments, for these have aesthetic, recreational, educational and scientific values to man." The integrity and biological diversity of prairie, savanna, and some forest ecosystems within the park require periodic fire. Designing and implementing a plan to utilize fire as a management tool and scientifically monitor the results is necessary for the park to achieve resource management goals.

2.4 Resource Management Plan Objectives

The project statement which addresses FMP development (MACA-N-080) begins with the following: "The National Park Service is committed

to maintaining and restoring ecological processes that existed before settlement within park lands, if there is good evidence for these processes, and if there are no serious conflicts with other management needs mandated at each park site". The objectives listed in the proposal are to 1) provide evidence of pre-settlement fire regime, 2) provide a geographic delineation of park sections that were probably influenced by fire before settlement, and 3) provide a detailed plan for implementing prescribed fire in appropriate areas of the park. Vegetation mapping is covered in project statement MACA-N-053 which recommends that: "A current vegetation map should be prepared that will sufficiently meet the park's needs for monitoring, protection and management of vegetative resources including unique, rare, threatened, or endangered species." The GIS-based vegetation map of the park produced for the Fire Management Plan provides a condensed classification of communities relevant to fuel types. The acreage of each community type has been tabulated for each Fire Management Unit and Prescribed Fire Area by the park GIS Specialist in Appendix 2.

2.5 Role of the Fire Management Plan in Meeting Objectives

Upon approval, the FMP will permit fire management in the park to expand operations beyond suppression to include prescribed fire. The restoration of fire as a natural force will have manifold ecological benefits, and at the same time will increase safety to the visitor, firefighter, and infrastructure alike. Prairie and especially savanna ecosystems will increase significantly from their virtually non-existent current status, and the dangers of uncontrollable wildfire associated with fuel build-up will be significantly reduced.

3.1 Overview of Karst Landscape and Component Ecosystems

3.0 Description of Mammoth Cave National Park

The 52,830 acres of Mammoth Cave National Park are part of a regional karst landscape, which is characterized by subterranean drainage (see Figure 1). From the southeast to the northwest corners of the park, there is a gradient of decreasing maturity in karst development, which corresponds to the regional dip of the bedrock. The major cave-bearing limestones are just barely exposed in the northwest part of the park, and so cave development there is in the earliest stages. The Green River runs east to west through the park, and is joined by the Nolin River from the north near the park's western border. These rivers are the hydrologic base level for drainage within the park.

Within the regional karst landscape, there is one historical and three functioning ecosystems. Historically, prairie bordered by savanna covered large portions of the Sinkhole Plain located south of the park. Karst valleys within the dissected upland of the Mammoth Cave Plateau offer a similar habitat type to the Sinkhole Plain, but no historical descriptions of pre-settlement vegetation have been found. Soon after settlement in the late 1700s, the grasslands described were largely converted to agriculture. Except for the loss of savanna (due to fire suppression), other ecological components of the karst landscape in the park are reasonably intact. The river ecosystem supports a highly diverse fish (82 species) and invertebrate fauna (250 species) of which over 50 species are freshwater mussels. The cave ecosystem, containing both aquatic and terrestrial components, is perhaps the most diverse in the world with over 130 regularly occurring species. Finally, the forest ecosystem has exceptional diversity as well with 82 species of trees in a variety of riparian and upland communities. An unknown percentage of currently forested land in the park would have been maintained as savanna and possibly some prairie via natural and Native American set fire. Diversity of plant species in the park has almost certainly suffered due to forest succession in the absence of fire, yet over 1100 kinds of plants have been identified to date. Sorted among terrestrial communities according to habitat preferences, 203 species of birds, 43 species of mammals, 29 species of amphibians, and 38 species of reptiles have been reported from the park. Data on other taxa, such as terrestrial invertebrates and fungi, are lacking. The species data for Mammoth Cave National Park is maintained in NPSpecies, a database developed by the National Park Service's Inventory and Monitoring Program in 1999 (see Appendix 3).

Functionally, since sinking streams and cave streams are tributaries of base-level rivers by way of springs, they are all part of the river continuum, with the important distinction that the middle section is underground. These distinct but connected aquatic ecosystems are energetically supported by in-washed organic debris from the forest/savanna and former barrens ecosystems. Food transport is usually down gradient, but natural back flooding from the river through springs into the lower cave streams is also important. As base level rivers lower their channels, cave streams follow and leave dry upper levels. These passages become habitat for the terrestrial cave ecosystem, which is also dependent upon the forest/savanna and former barrens ecosystems for its food base. The import of food is mostly accomplished by cave crickets, bats, and packrats which feed in the forest/savanna above, and use caves for refuge where their guano accumulates.

Clearly, all of the component ecosystems within the karst landscape are functionally connected and must be managed holistically in order to realize our restoration goals. Fire is obviously a powerful determining force in vegetation communities. Whether a given area with fire potential is prairie, savanna, or forest is governed largely by fire regime, and these vegetation types define habitats, including food supply, for a broad spectrum of wildlife. For the river and connected aquatic cave ecosystem, vegetation determines the amounts and quality of water, sediment, and organic matter that enter. For the terrestrial cave ecosystem, the types and quantities of insects, fungi and plants available to bats, woodrats, and cave crickets are largely determined by major vegetation types sculpted, in part, by fire.

3.2 Overview of Cultural Resources

There are over 1,008 identified prehistoric and historic archeological sites in the park representing almost 10,000 years of human history. The museum collection contains more than 150,000 objects including the Hercules Engine and Combination Car, which are listed on the National Register of Historic Places. Additional National Register listings include 28 structures and one archeological site. Based on radiocarbon dates of cultural material, prehistoric people entered

Mammoth Cave and other park caves almost 4,000 years ago to explore and mine cave minerals. Mammoth Cave was first recorded by Euro-Americans in the late 18th Century and was mined for saltpeter during the War of 1812. Guided tours began in 1816, and until 1926, when legislation to establish Mammoth Cave National Park was passed, the cave was operated as a tourist attraction by a succession of private owners. Mammoth Cave became a National Park in 1941 and was listed by UNESCO as a World Heritage Site in 1981 due to its cultural significance (Ward 1999).

3.3 Surface Habitat Types in the Park

Taking regional geography and hydrology into account, a vegetation habitat classification has been developed for Mammoth Cave National Park (Olson and Franz 1998). This habitat classification combines bedrock geology, slope, and aspect in the park's Geographic Information System (GIS) with a spatial resolution of 30 meters (see Figure 2). The underlying rationale is that for a given climate, bedrock geology largely determines soil type, and whether surface or subsurface (karst) drainage prevails. Soils on calcareous (calcium containing) bedrock are pH buffered as the underlying rock is dissolved; soils on non-calcareous rocks tend to be more acid due to the lack of buffering. Because of this, the Kentucky State Nature Preserves Commission classifies habitats as "calcareous" or "acid" based upon bedrock type, and this plan follows their convention. Due to the tendency for subsurface drainage to develop in calcareous bedrock such as limestone, virtually any site with a given set of geographic characteristics will be more xeric (dry) than an equivalent situation underlain by insoluble rocks such as sandstone or shale. The magnitude of this general difference appears to be minimized on the steepest exposures due to rapid surface drainage. Slopes were divided into three categories that would yield ecologically significant zones on the GIS display using a Digital Elevation Model. The 360 degrees of aspect were grouped into 16 wedges of 22.5 degrees each. For the Moderate and Steep slope categories with Calcareous or Acid geology, aspects were based upon the sum of relevant wedges. These values are displayed as pie diagrams included in Appendix 4 along with the full array of habitat types based upon physical attributes.

One significant attribute of the habitat map is that natural physical influences on vegetation types are made clear, and in a quantitative way that is not attainable by direct study of geological quadrangle maps (see Table 1). This is especially important given the complex history of cultural disturbance over the past two centuries since settlement, and the profound impact on vegetation patterns seen today. For example, the vast majority of coniferous forest stands in the park today are linked to pre-park agriculture (see Figure 3). Local environmental conditions amenable or inimical to fire are controlled directly and indirectly by the factors that determine habitat type. All habitat types in the park are variously prone to fire with the exception of the Calcareous Mesic class, Alluvium (floodplain), and the two Supra-Mesic classes. At over 9000 acres, the Calcareous Mesic habitat type is important for two reasons: the change in fuel type on these shaded slopes (Tim Sexton pers. com.), and the great linear extent of these habitat patches will impede the progress of fire across the landscape (see Figure 2).

3.4 Condensed Vegetation Map of the Park

Vegetation in the park has been classified into seven categories, and mapped (see Figure 3) based upon individual sorting of 200 Landsat

Table 1. Areal Extent of Habitat Classes in the Park
Habitat types in bold are capable of carrying fire during the spring and fall fire seasons. These habitat types account for approximately three fourths of the park.

Habitat Type	*Acreage*	*% of Total Acreage*
Calcareous Xeric	150	<1
Calcareous Sub-Xeric	15,400	30
Calcareous Mesic	9,050	18
Calcareous Supra-Mesic	130	<1
Acid Xeric	60	<1
Acid Sub-Xeric	2,500	5
Acid Mesic	20,000	40
Acid Supra-Mesic	1,000	2
Alluvium	2,700	5

satellite spectral data channels using the habitat map as a guide (Olson et.al.2000). This vegetation classification is condensed in order to facilitate designation of fuel types for fire management.

In subxeric deciduous forest, chestnut oak and chinkapin oak sort very distinctly with sandstone and limestone substrates respectively, whereas blackjack and post oaks are less selective. With periodic fire, these forest stands may have been a more open woodland or savanna in the past. On the map in Figure 3, both red and orange are shown for this vegetation type since the red spectral class most often indicates the presence of chestnut oak. Much of the relatively level plateau fragments, (locally called ridges) which will someday support oak-hickory forest and savanna, were in agricultural use prior to park establishment. Exceptions to this generality are the Big Woods and Collie Ridge north of Green River, and much of the Mammoth Cave Estate visible in Figure 3 as a prominent yellow area on Jim Lee and Mammoth Cave Ridges. Within these mesic upland oak-hickory forests, the chemical and hydrological influence of relatively thin limestone units (currently classified as calcareous subxeric habitat) interbedded with sandstone on the ridges is muted in comparison with the thick limestone beneath karst valleys. This is due to weathered sandstone residuum on top of the limestone, and the limited degree of karst development possible. Karst usually leads to drier surface conditions due to subsurface drainage, but (paradoxically) upland swamps perched on sandstone may have originated as sinkholes in these thinner units such as the Haney limestone. Unfortunately, these upland swamps with stands of pin oak, sweetgum, and red maple are too small to be mapped at the 30 meter resolution of Landsat imagery.

Table 2. Vegetation, Habitat Types, and Typical Species

Habitat type nomenclature follows the Kentucky State Nature Preserves Commission system. "Acid" refers to non-carbonate bedrock, which results in acid soil, and "calcareous" refers to carbonate bedrock, which results in more alkaline soil. Xeric refers to dry areas, mesic to moist, and alluvium to river lain sediments.

Vegetation	*Habitat Type*	*Typical Species*
1. Subxeric Deciduous Forest/Savanna	Acid Subxeric Calcareous Subxeric	Chestnut Oak Post Oak Chinquapin Oak Blackjack Oak Post Oak
2. Mesic Upland Deciduous	Acid Mesic Calcareous Subxeric	White Oak Pignut Hickory Black Oak Tulip Poplar
3. Mesic Hollow/ Floodplain Deciduous Forest	Calcareous Mesic Acid Mesic Alluvium	Sugar Maple Beech Box Elder Sycamore
4/5. Mixed Deciduous Coniferous Forest Mixed Coniferous/ Deciduous Forest	Acid Mesic Calcareous Subxeric Alluvium	Red Maple Tulip Poplar Dogwood Sweetgum Cedar/pine
6. Coniferous Forest	Acid Xeric to Mesic Calcareous Xeric to Subxeric	Virginia Pine Eastern Red Cedar
7. Prairie/Open Area	Calcareous Subxeric	Native Grasses and Forbs Mown Grass

Mesic hollow forests are most prominent in ravines directly connected with the Green and Nolin River Valleys, but outliers exist in karst valleys in the bottoms of large sinkholes. In addition to beech and maple, black cherry, and black walnut can be locally prevalent. In exceptionally moist hollows mostly found in the northwest extremity of the park, relict stands of hemlock and yellow birch are found. These also are too small to map at 30 meters resolution. Floodplain forests are characterized by sycamore, silver maple, and river birch on river banks, and box elder slightly further from the water. Mesic hollows are relatively undisturbed due to the lack of flat ground, which cannot be said for the once heavily farmed floodplain. Being superbly adapted to the highly disturbance-prone gravel bar habitat, sycamore trees are also found wherever significant disturbance has occurred, such as along roads.

Mixed deciduous/coniferous (and vice versa) forests in the park are overwhelmingly successional after pre-park pasture and row crop use. These old fields are generally located in acid mesic habitats (with some interbedded limestones as discussed above) on relatively level uplands, in calcareous subxeric habitat found in karst valleys, and on floodplain alluvium. In mixed xeric communities/habitat types, virginia pine is typically associated with chestnut oak, and eastern red cedar with chinkapin oak. Many of these stands appear to be virgin in contrast to the profoundly disturbed old fields. On xeric limestone sites, solutional features called rillenkarren indicate that the thin soil and exposed bedrock is not due to post settlement erosion. The successional trajectory for old field forests is reasonably clear on the uplands (oak-hickory forest/savanna), and the floodplain (sycamore-boxelder), but in the karst valleys pre-settlement vegetation types are not known. Shingle oak is largely restricted to karst valleys, so this species may have been prevalent.

Coniferous forests in the park, like the mixed stands previously discussed, are overwhelmingly successional after pre-park agriculture. Stands in karst valleys are dominated by eastern red cedar, and those on sandstone uplands are mostly virginia pine, but considerable mixing occurs. Whether the stands are cedar or pine, indications of ecological succession are visible on the map (Figure 3). Commonly on the uplands around a nucleus of coniferous forest, a zone of coniferous/deciduous forest is found, which is followed by a zone of deciduous/coniferous vegetation, transitional to oak-hickory forest. All elements are not present in each case, but forest succession is clearly documented. In the big karst valleys, the current successional trajectory is less clear. In the absence of fire, the karst valleys could easily become a subxeric oak-hickory forest with mesic hollow species in the sink bottoms.

Prairie in the park is limited to small areas each no greater than 40 acres, and none can be considered actual remnants from presettlement times. Even so, these areas are rich in prairie grasses and forbs such as big bluestem, Indian grass, goldenrod, and tall coreopsis. They serve as refuges for species marginalized by conversion of former prairie on the sinkhole plain to agriculture, and by fire suppression within and beyond park boundaries (Seymour 1997). Other open areas in the park are largely mown roadsides, cemeteries, and lawns around developments maintained in fescue.

3.5 Values to be Protected

Mammoth Cave National Park is a World Heritage Site and an International Biosphere Reserve. This is due to 1) the outstanding karst development including Mammoth Cave, which at 350 miles is the longest known cave system in the world, 2) world-class archeological resources, and 3) the highly diverse assemblage of cave fauna.

Cultural resources from a given era gradually diminish with time. It is our responsibility to avoid hastening that loss rate, and to retard it where warranted. Time is the one continuous fabric that links us with previous cultures throughout the Mammoth Cave area. The relatively few artifacts that survive into modern times help us understand those who came before us, and someday we may use this understanding to avoid repeating mistakes. In addition to the historic structures such as community churches, there are modern park facilities including a visitor center, hotel, campgrounds, picnic area, residential area, offices, ranger station, and a research center.

Water, flowing either in the Green and Nolin Rivers, or through the cave streams, is the single-most unifying resource at Mammoth Cave. The quality of these waters is of highest importance to not only regulatory agencies – considered an Outstanding Resource Water by Kentucky, and one of the fundamental reasons of the establishment of the park as described in accounts of the Southern Appalachian National Parks Commission – but also to the dependent aquatic ecosystem.

The U.S. Fish and Wildlife Service identified the species considered in this document by letter dated July 12, 2001 as known to occur or with the potential to occur within Mammoth Cave

National Park.[1] The park is located in portions of Barren, Edmonson, and Hart Counties in Kentucky.

Mammoth Cave National Park is designated as a mandatory Federal Class I area under the provisions of the Clean Air Act, as amended in 1977 and 1990. The designation provides the greatest degree of air quality protection with very little deterioration of air quality allowed. The mandatory Federal Class I area designation provides many benefits to the air quality related values of the park including 1) the health of residents and visitors to the region, 2) the health of vegetation and wildlife, and 3) the protection of scenic views.

4.1 Archaeological Indicators of Pre-settlement Fire

Miles of cave passages within the park contain abundant artifacts left by Native Americans, mostly between 2000 and 3000 years ago. Much of this ancient material consists of plant remains from various uses, and these artifacts provide insight into some pre-settlement vegetation

Listed Endangered Species

Indiana Bat	*Myotis sodalis*[2]
Gray Bat	*Myotis griescens*
Red-cockaded Woodpecker	*Picoides borealis*
Bachman's Warbler	*Vermivora bachmanii*
Kirtland's Warbler	*Dendroica kirtlandii*
Kentucky Cave Shrimp	*Palaemonias ganteri*[2]
Rough Pigtoe Pearly Mussel	*Pleurobema plenum*
Clubshell	*Pleurobema clava*
Ring Pink	*Obovaria retusa*
Fanshell	*Cyprogenia stegaria*
Pink Mucket Pearly Mussel	*Lampsilis orbiculata*
Northern Riffleshell	*Epioblasma torulosa*
Orange-footed Pearly Mussel	*Plethobasus cooperianus*
Cumberlandian Combshell	*Epioblasma brevidens*
Fat Pocketbook	*Potamilus capax*
Tuberculed-blossom Pearly Mussel	*Epioblasma torulosa torulosa*
Purple Cat's Paw Pearly Mussel	*Epioblasma torulosa sulcata*
Cracking Pearly Mussel	*Hemistena lata*

Listed Threatened Species

Bald Eagle	*Haliaeetus leucocephalus*
Eggert's Sunflower	*Helianthus eggertii*
Price's Potato Bean	*Apios priceana*

Proposed Species

Scaleshell	*Leptodea leptodon*

Candidate Species

Surprising Cave Beetle	*Pseudanopthalmus inexpectatus*
Beaver Cave Beetle	*Pseudanopthalmus major*
Clifton Cave Beetle	*Pseudanopthalmus caecus*
Cumberland Johnny Darter	*Etheostoma nigrum ssp. Susanae*
Fluted Kidneyshell	*Ptychobranchus subtentum*
Greater Adams Cave Beetle	*Pseudanopthalmus pholeter*
Icebox Cave Beetle	*Pseudanopthalmus frigidus*
Lesser Adams Cave Beetle	*Pseudanopthalmus cataryctos*
Louisville Cave Beetle	*Pseudanopthalmus troglodytes*
Short's Bladderpod	*Lesquerella globosa*
Slabside Pearlymussel	*Lexingtonia dolabelloides*
Tatum Cave Beetle	*Pseudanopthalmus parvus*
White Fringeless Orchid	Platanthera integrilabia

[1] Barclay, Lee A. Field Supervisor, U.S. Fish and Wildlife Service, Kentucky/Tennessee Field Office. Letter to Ronald R. Switzer, Superintendent, Mammoth Cave National Park. July 12, 2001.

[2] Critical habitat has been established within the park for these species.

characteristics under similar climatic conditions. Data on pollen, recovered during archaeological investigation of Salts Cave in the park, (Watson et al. 1974) indicate an abundance of lambs quarters in samples dated between 3000 to 3500 years before present (BP), followed by peaks in grasses and ragweed in strata above (still probably ca. 3000 years BP). The same study revealed an increase in the occurrence of edible annual weed seeds in human paleofeces, including much lambs quarters, sunflower, sumpweed, amaranth, panic grass and maygrass. These plant remains indicate that vegetation conditions other than closed canopy forest existed since light intensity on the ground would have been inadequate. Use of fire to maintain openings in the forest would be consistent with practices elsewhere in eastern North America (Olson 1996). Prentice (1993) acknowledged a heavy emphasis on horticulture by prehistoric populations, but did not discuss fire.

Three types of plant stems were primarily used for torch fuels in local caves by Native Americans: cane, false foxglove, and goldenrod (Watson 1969, 1974). Olson (1998) noted that false foxglove was used dominantly in some park caves, and that false foxglove is partially parasitic on the roots of oak trees (Pennell 1935). Musselman and Mann (1978) induced root parasitism with other tree species, but noted that large natural populations are found at the margins of oak stands. Given this parasitic relationship, and the simultaneous requirement for adequate light if plant stems are to grow tall enough for use as torch material, then oak savanna or openings bordering oak stands must have been much more prevalent than today since false foxglove is very infrequent in the park (Seymour 1997). Oak savanna is a largely fire-dependent community, and the presence of this community type would be consistent with observations on the probable prehistoric slash and burn plant cultivation documented in the vicinity of Salts Cave. In Lawrence County, Ohio, ecological restoration via prescribed fire has resulted in significant increases in the abundance of false foxglove and other herbaceous species (Hutchinson 2000). This is consistent with the archaeological evidence at Mammoth Cave National Park.

Cane is primarily a lowland species in the region today, being largely confined to the Green River corridor and major tributaries. Watson (1969) noted cane torch remnants up to one inch in diameter, and that modern cane this size could not be found. She concluded that this cane likely came from bottomland sites under cultivation for edible species. Olson (1998) pointed out that cane was once much more widespread based upon the Filson Map of Kentucky (1784), and that the growth of large cane in a variety of habitats would simply require less competition; especially more light. The same situation would apply to goldenrod since it can only grow to a size useable for torches with adequate sunlight.

Archeological remains of slippers worn by Native American miners and explorers in portions of the Mammoth Cave System (Watson 1969; King 1974) were often manufactured from leaves of rattlesnake master. This species is restricted to savanna and prairie communities, and is currently very limited within the park. Though it is possible that rattlesnake master was harvested on the Sinkhole Plain and transported up to the Mammoth Cave Plateau, this species would have been much more abundant in savannas and glades on the plateau than it is today.

All of the food plants described above, the large plant stems used for torch materials while exploring and mining in caves, and the plants used for slipper material require more light than what is available in park forests today. In the tiny areas within the park where these species are currently found (some actual habitat remnants and others artificial such as roadsides), their populations are severely limited. This scarcity compared with past abundance indicates that much less closed–canopy forest existed then compared with now, and modern suppression of fire is the most probable explanation.

4.2 Historical Vegetation Descriptions Relevant to Fire

The earliest historical description of vegetation on the Mammoth Cave Plateau was by Botanist Francois Michaux (1805) in 1802, and this was limited only to the view up from the Sinkhole Plain, most likely near Dripping Springs in Edmonson County, which is just southwest of the park: "The surface of these meadows is very even; towards Dripping Spring I observed a lofty eminence, slightly adorned with trees, and bestrewed with enormous rocks, which hang over the road…." The maintenance of prairie vegetation on the Sinkhole Plain by fire is very well documented, and Michaux stated: " Every year,

in the course of the months of March or April, the inhabitants set fire to the grass, which at that time is dried up…. The custom of burning the meadows was formerly practiced by the natives, who came to this part of the country to hunt." Michaux's description of savanna on the Mammoth Cave Plateau at the Chester Escarpment is further supported by place names on USGS Quadrangles in the Park City and Cave City vicinity such as Bald Knob, Brushy Knob, and Huckleberry Knob.

The earliest description of vegetation on the plateau away from the Chester Escarpment is by Alexander Bullitt. In the introductory chapter of an 1844 visitors guide to Mammoth Cave he wrote: "For a distance of two miles from the Cave, as you approach it from the South-East, the country is level. It was, until recently, a prairie, on which, however, the oak, chestnut and hickory are now growing; and having no underbrush, its smooth, verdant openings present, here and there, no unapt resemblance to the parks of the English nobility." The two mile distance from the cave corresponds closely to the southern boundary of the Mammoth Cave Estate, which indicates land-use rather than a natural ecological origin for the former putative prairie become savanna, which is today a dense oak-hickory forest in mid to late succession. Other factors to bear in mind are that 1) this description is approximately 50 years post settlement, and 2) Mammoth Cave was intensively mined for saltpeter during the War of 1812. The process required a steady supply of firewood for the boiling furnaces, and yet more wood for production of fixed alkali (potassium hydroxide) used in the manufacturing process. Consequently, trees were cut from many acres of land for miles around in order to meet the demand (Faust 1967).

Hussey (1876) conducted a survey of plants in Barren and Edmonson Counties, and observed that Buffalo Clover *(Trifolium reflexum)* "occurs in several localities between the railroad and Mammoth Cave…I mention it because I have never found so many specimens in any one locality before, and also to make note of the fine rose-pink color it everywhere had."

DeFriese (1880) reported in his 1878 timber survey across Kentucky: "On leaving Glasgow Junction [now Park City], toward Mammoth Cave, plenty of white oak is found in the sinks; post oak, black oak, scarlet oak, and red oak are found on the higher grounds, and as soon as the Chester sandstone, which caps the so-called hills, is reached, chestnut is found in great abundance. This is the first chestnut worthy of note found, and all that has been found, so far [from the Mississippi River to here], if a few bushes on the silicious limestone, near the Tennessee river, be excepted; though doubtless all this Chester sandstone, from Hopkinsville to Glasgow Junction, would have been covered with it, but for the fires that long ago swept over this richly timbered country, year after year, and drove its choicest trees from the forests".

"Again, forest fires have not denuded certain portions of the country in the neighborhood of Mammoth Cave. What is known as Doyle Valley for instance, has been, for some reason, largely protected from the ravages of fire, even if the entire district has not been. From the growth of chestnut I am inclined to think it has never been continuously burned over…On the hill sides facing Doyle's Valley the trees are magnificent, and white oak, liriodendron, white hickory, massive chestnut, scarlet oak, red oak, black oak, Spanish oak, chestnut, ashes and redbud &c., abound. The chestnut, however, is limited to the sandstone and stops abruptly when the limestone is reached descending the hill." DeFriese's conclusion that Doyel Valley experienced a lower fire frequency based upon the growth of chestnut trees is a bit confusing since he clearly states that the chestnuts were only to be found on or near sandstone substrate which is limited to the valley rim. Another caveat to bear in mind is that these observations were made approximately 90 years post settlement.

The observations of Michaux, Hussey, and DeFriese are especially useful. The forest on the Chester Escarpment at Dripping Springs and everywhere else today has a solid canopy, and bears no resemblance to the savanna Michaux described. Buffalo Clover is a savanna or forest edge species, and even though Hussey's survey was conducted approximately 80 years post settlement, the multiple occurrences indicate that this species, and therefore its habitat, was formerly widespread. Today, Buffalo Clover is "extremely rare" in the park Seymour (1997). In both cases, the observed botanical changes over time are consistent with the effects of fire suppression. DeFriese observed the abundance of post oak (among others) in the area where Diamond Caverns is located today. Magnificent specimens of this extremely fire tolerant tree, old enough for DeFriese to have seen when he passed through, are still found nearby. As well, he was specific in pointing out where the effects of fire appeared less manifest (Doyel Valley), and in doing so clearly implied that fire effects were more general in the Mammoth Cave vicinity.

4.3 Fire Ecology

Study of pollen cores from Jackson Pond, located about 30 miles northeast of Mammoth Cave on the Sinkhole Plain (less than a mile from the Chester Escarpment), indicates that from about 3900 years before present the region had a mix of prairie and deciduous forest. Whether the prairie had its origins in climatic change, or was the result of human actions is not known (Wilkins et al. 1991 p.236-7). When Michaux described the annual spring fires on the Sinkhole Plain in 1802, a primarily cultural source of ignition was apparent to him. Ray (1997 p.188) acknowledged the role of Native American set fire in the maintenance of prairie and savanna, but also made a convincing argument for the importance of lightning ignited fire as a force affecting vegetation patterns in the Mammoth Cave area. Oak ecosystems in eastern North America have co-evolved with fire (Abrams 1992, Olson 1996), and the relationship between savanna and oak forest has only recently been recognized. Some compilations of the distribution and status of the oak hickory, savanna complex don't acknowledge that the type occurs in Kentucky, but more recent treatments depict the Mammoth Cave region as having been a mixture of savanna mixed with prairie and forest.

There are two fire seasons in the Mammoth Cave area, one in spring from February 15th to April 30th, and the other in fall from October 1st to December 15th. Given that many herbaceous plants remain alive and even bloom into late October (Seymour 1997), fuels are not as consistently dry in fall as in the spring, and leaves do not typically finish dropping until late October. Other points favoring the spring fire season over fall are that the effects of spring fires are generally more beneficial to many types of wildlife since the seed crop of the previous growing season has already been consumed and/or dispersed during the winter, and nutrients from the ash are less likely to be washed away before germinating plants can absorb them. The annual spring fires described on the Sinkhole Plain by Michaux would tend to propagate up the Chester Escarpment, which faces primarily south in the Mammoth Cave area. This southern aspect of the escarpment is conducive to drying fuels, and since the prevailing wind is from the south (see Appendix 5), the escarpment would function as an excellent fire ladder to the Mammoth Cave Plateau. DeFriese's observation of post oak between Glasgow Junction (Park City) and the escarpment is consistent with frequent fire.

Fire ecology of the park south of Green River can most reasonably be described in two sections divided near Turnhole Spring on Green River (see Figure 4). East of Turnhole Spring, the park is characterized by mature karst which includes the Mammoth Cave System plus other major caves, and very limited extent of perennial surface streams. Large segments of the plateau including Joppa Ridge, Mammoth Cave Ridge, and Flint Ridge are relatively level and well drained except for isolated wetlands with vernal pools, and short spring runs. The only major barriers to northerly propagation of fire in this sector of the park are the shaded Calcareous Mesic slopes described above in 3.3 which serve as fuel breaks (see Figure 2) where fire would be required to burn down slope into fuels with greater moisture content. Isolated patches of particularly xeric habitat on slopes with high sun exposure will also retard fire due to low amounts of fuel. Similarly, outside the southern boundary of the park there are few barriers to fire on this highly dissected portion of the Mammoth Cave Plateau known as "The Knobs" due to lack of surface streams, and also due to extensions of the Sinkhole Plain into the escarpment.

The southern edges of Woolsey and Doyel Valleys are only about two miles from the Chester Escarpment, and therefore close to a reliable annual pre-settlement ignition source (see Figure 1). In the Park City area, fingers of the Sinkhole Plain cut into the escarpment and narrow the gap to within a half-mile. These valleys have the same karst hydrogeology that exists on the Sinkhole Plain, therefore, no surface streams are present to inhibit the spread of fire. Based upon the foregoing, it is conceivable that the annual spring fires on the Sinkhole Plain spread into these two valleys at some frequency. Unfortunately, we have no early historical information on vegetation or fire frequency in these or any other karst valley in the park. DeFriese's conclusions on Doyle Valley did not support frequent fire, but being roughly 90 years post settlement, the appearance at that time could just reflect land use preferences. An attempt to find silica phytoliths and charcoal in soil as indicators of past vegetation type and fire regime had negative results (Kaliz 1997). Carbon and oxygen isotope studies of speleothems in cave passages underlying these karst valleys can provide information on major vegetation type and climate (Dorale et al. 1998), and these will be pursued in the future.

The eastern edges of Houchins Valley (including contiguous Eaton and Strawberry Valleys) and the smaller karst valley leading to Dennison Ferry are both over four miles from the Chester Escarpment, and not directly downwind from the documented annual fires on the Sinkhole Plain. Therefore, it is less likely that fire from the Sinkhole Plain propagated into these valleys when compared with Woolsey and Doyel Val-

leys. Ignitions in Houchins Valley via cultural or natural sources would easily spread up onto Flint Ridge and propagate north with the prevailing southerly winds. Ignitions from lightning are possible on any of the ridges, and lightning scars on trees are common.

West of Turnhole Spring and south of Green River, park lands are in a much earlier stage of karst development. A "layer cake" of inter-bedded limestone and sandstone causes surface streams to be present on a segmented basis as water sinks into limestone, and reappears on sandstone at springs. Only minor cavernous development in the underlying massive limestone beds that contain the Mammoth Cave System has taken place. Because much of the drainage southeast of the boundary flows toward Beaverdam Creek instead of Green River in the park, the streams in this sector are small. The Mammoth Cave Plateau west of Turnhole Spring is reasonably intact, and large, level areas are separated by relatively narrow ravines. Notable exceptions to this general condition are prominences of sandstone such as Brooks and Crumps Knobs, and Indian Hill.

Beyond the southern border of the park west of Turnhole Bend, there are two natural barriers to fire propagating from the Sinkhole Plain. First, the distance from the border to the escarpment is approximately five miles, and second, Beaverdam Creek cuts west to Green River across the Mammoth Cave Plateau (see Figure 1). Both distance and surface water decrease the probability of continued fire propagation. Once past the creek however, there would be little to stop a fire propelled by southerly winds until Green River.

Green River is an obvious major firebreak between the north and south halves of the park. Not only is the water a barrier, but the south shore is largely bordered by Calcareous Mesic habitat not conducive to fire. Whether this firebreak effect of the river caused a major difference in fire frequency between the two sides is unknown, and therefore a hypothesis to be tested. Certainly Native Americans lived on both sides of the river, and it is hard to imagine that they set fires with greater frequency on one side versus the other. Carefully matched Fire Management Areas have been selected on either side of the river as one way to test the river firebreak effect hypothesis.

Fire ecology of the park north of Green River can most reasonably be described in two sections divided along the Dry Prong of Buffalo Creek (see Figure 4). West of the Dry Prong, karst development is limited in much the same way as described for the area west of Turnhole Spring and south of Green River. Perennial surface streams tributary to the Nolin River, such as Bylew and Second Creeks, dissect the landscape more than any other area in the park. Drainage areas in the northwest sector are greater than those in the southeast, and stream valleys are deeper, so even with alternating surface and subsurface flow, First Creek and the Wet Prong of Buffalo Creek constitute significant fire breaks. The landscape is characterized by steep outcrops of sandstone with relatively long and level but narrow ridge tops. The sunny sides of these outcrops have the largest patches of Acid-Sub-xeric habitat in the park, which supports forest communities dominated by Chestnut Oak, and Acid-Xeric habitats on cliff edges, where Virginia Pine/Chestnut Oak communities are found. The northerly slopes of these same ridges have the greatest extent of Acid Supra-Mesic habitats in the park which support relict stands of hemlock, yellow birch, and other species. Given the presence of surface streams, and rough terrain with moist north-slope habitats, fire is not likely to propagate great distances except along north-south oriented ridges. On these prominent ridge tops, lightning scars are common, and in the Xeric to Mesic habitats, fire can be locally intense whatever the orientation or ignition source.

From the Dry Prong of Buffalo Creek to the east park boundary, karst development is manifest. There are several significant cave systems north of Green River, and Buffalo Creek Cave, which takes the flow of the Dry Prong, is westernmost. With the exception of Cub Run, which is aligned with a major fault, surface streams are limited to small segments that originate at springs perched on sandstone. The terrain is moderate, typical of the Mammoth Cave Plateau, and is cut by ravines or hollows. The large karst valleys found directly south across Green River are not present due to the dip of the limestone; the massive cave bearing limestone layers such valleys develop in are just being exposed in the hollows, and along Green River. Acid and especially Calcareous Xeric habitats are prominent on the bluffs with a southerly aspect above the north shore of Green River. On the plateau fragments, Acid Mesic and Calcareous Sub-Xeric habitats prevail except for isolated sandstone prominences with Acid Sub-Xeric habitat. A fire ignited on the gooseneck of Turnhole Bend, for instance, could well be propelled to the northern park boundary with a wind from the south. Depending on their orientation, the ravines can provide excellent habitat for fire-dependent vegetation communities. As an example, the Goblin Knob area has substantial Acid and Calcareous Sub-Xeric habitat area.

Considering the full range of habitats modeled and mapped in Mammoth Cave National Park, over 40,000 acres or about 75% of park lands are capable of carrying fire under the normal range of weather conditions during the fire seasons (refer to section 3.3 for details). Due to the large annual fires that maintained prairie on the Sinkhole Plain, fire may have been more frequent in the park south of Green River due to the fire break capability of the stream and valley. However, on both sides of the river lightning and human caused ignitions may have negated any potential fire break effect. We must consider also that the ridge to ridge distance across Green River at several points, such as the north extremity of Joppa Ridge, is 0.3 miles, and it would not be impossible for sparks and embers to be carried across to the north shore during a hot fire.

4.4 Post Park Fire History

Since the park was established, most wildfires have been caused by arson, careless smoking, escaped campfires, or escaped debris pile fires. However, park fire history files report the first lightning caused fires in 1937 (Ray 1997). At least nine lightning fires have been recorded since that time. Reporting and documentation are inconsistent and for many years of fire reporting, the cause is not recorded, but known fires are displayed in Figure 5. Over time as the FMP is implemented, canopy density will likely decrease, fine fuels on the forest floor will increase, and therefore lightning caused fires may become more frequent. Approximately 45% of park land was formerly cleared for agricultural purposes including row crops and pasture. These old fields are now in early to mid succession, and depending upon the habitat type range from low to high inflammability. Forest stands in some old fields on Floodplain Alluvium habitat have progressed through secondary succession rapidly, and have little fire potential. On the other hand, dense stands of eastern red cedar and Virginia pine in Calcareous Sub-Xeric habitat within the large karst valleys could easily produce fires of unnaturally high intensity and severity. Due to park policy, all wildfires have been suppressed since the park was created. An approved Fire Management Plan is needed prior to any other fire management action due to the potential negative impacts of unwanted fire.

5.1 Fire Management Goals

The overarching goals of resources management at Mammoth Cave National Park are to maintain and restore ecological processes that existed before settlement within park lands while preserving cultural resources, and simultaneously assuring the safety of local residents, visitors, firefighters, park staff, and infrastructure alike. These goals are consistent with the Strategic Plan, and no fire management action will be taken without a substantial safety margin.

5.2 Fire Management Objectives

5.0 Park Fire Management Goals and Objectives

A. Suppress all wildland fires. Any wildland fire within and adjacent to park boundaries will be suppressed using the appropriate suppression response necessary according to the judgement of the park superintendent and cooperating agencies. Safety and protection of people and property will be insured in the conduct of these operations.

B. Conduct a prescribed fire program. Within designated Prescribed Fire Areas, restore fire as an ecological process, and/or reduce hazard fuels within the conditions of carefully crafted prescriptions. Safety and protection of people and property will be insured in the conduct of these operations.

C. Raise public awareness of fire management program goals and objectives.

D. Establish and/or maintain cooperation with fire departments around the park.

Incorporate knowledge gained via fire effects monitoring and related research into fire management plans and actions.

Investigate the possibility of utilizing fire of natural origin to achieve management goals based on information from the prescribed fire program and evaluation of fire effects. An effort will be made to acquire the skills necessary to implement such a strategy.

5.3 Strategies to Achieve Objectives

A. Suppress all wildland fires. All wild land fires will be suppressed using the appropriate management response. The appropriate management response will vary from fire to fire, and sometimes even along the perimeter of a fire. Methods used for suppression will minimize environmental impacts. For instance, fire lines will be constructed with hand tools rather than bulldozers except in the most extreme cases threatening life or valuable property. The use of natural and artificial barriers will be used to contain fires when appropriate.

Appropriate management response options range from monitoring with minimal on-the-ground disturbance to intense suppression actions on all perimeters of the fire. The appropriate management response is developed from analysis of local situations. Factors such as values to be protected, management objectives, external concerns, and land use need to be formally assessed. The first priority in all fire suppression operations is safety.

B. Conduct a prescribed fire program. This is primarily an ecological restoration program based upon archaeological and historical evidence of pre-settlement fire regimes. The prescribed fire program will be implemented based upon evidence of natural (including Native American ignitions) fire influence. A geographic delineation of park sections likely influenced by fire before settlement has been realized via GIS-based habitat modeling, hydrological mapping, and consideration of long-term weather data. A map of current vegetation in the park has been produced using satellite spectral data and the habitat map, and classification of fuels in the park via this map has been accomplished. Specific Prescribed Fire Areas are mapped within the park GIS system where restoration of fire as an ecological process is a priority. However, it must be stressed that the first priority in all prescribed fire operations is safety.

C. Raise public awareness of fire management program goals and objectives. Regionally, newspaper articles and other media will be used to introduce the Fire Management Plan to everyone from local residents to the state's tourism industry. Media coverage will be coordinated by the park Public Information Officer. Interpretive and Environmental Education programs on the ecological role of fire, the fuel reduction value of prescribed fire, and minimization of environmental impact from fire operations will be offered to local organizations, park staff, concessioners, visitors, school groups, and other users of the park. This work will be coordinated by the Chief of Interpretation and Visitor Services, and the Chief of External Programs.

D. Maintain cooperation with fire departments around the park. The park has Memorandums of Understanding with three local volunteer fire departments. These fire departments provide valuable assistance with initial attack and structure protection. In addition, the national park units in the state maintain general agreements with the Kentucky Division of Forestry.

E. Incorporate knowledge gained via fire effects monitoring and related research into fire man-

agement plans and actions. Restoring proper frequency and intensity of fire in the spectrum of relevant habitats in the park is a complex undertaking. The prescribed fire program will initially be limited so that feedback from fire effects monitoring and more detailed botanical research can be utilized on a broader landscape basis. This is imperative since the potential recovery time from mistakes spans many decades.

Wildland Fire Use is a strategy for allowing naturally ignited wildland fires, under prescriptive management, to burn as long as the fire meets pre-stated resource management objectives in predefined geographic areas. A wildland use fire that does not meet predetermined prescriptive elements or fails to meet resource management objectives would be suppressed using the appropriate management response.

Wildland Fire Use for achieving resource management objectives will not be a strategy employed at the present time. This strategy possibly will be initiated when this plan is revised in five years. This will allow the park to implement its prescribed fire program and make meaningful conclusions based on monitoring data. This program may be initiated only after the park has adequate data to make an informed decision concerning the appropriateness of this option.

6.1 Park Units in Relation to Prescribed Fire

The park is physically divided into northern and southern halves by the Green River, and each of these are further divided east-west on the basis of karst developmental maturity as described in 4.3 (see Figure 4). To the greatest extent possible, Fire Management Units (FMU) in each of these quadrants are designed as defensible polygons in the event of wildfire. With the exception of S6, each FMU has at least one Prescribed Fire Area (PFA) where prescribed fire is planned (see Figures 2, 3, and 4). There are 9 FMUs containing 16 PFAs north of Green River, and 11 FMUs with 33 PFAs on the south side. Habitat types, vegetation, and disturbance history relevant to the application of prescribed fire in PFAs will be considered by quadrant to facilitate discussion.

6.0 Wildland Fire Managment Situation

GIS-based data on PFAs, including previous fire history, are located in Appendix 2. It is important to note that while PFAs are delineated as a GIS data layer, the Burn Boss has considerable flexibility in placement of fire lines. More specifically, the actual perimeters of prescribed fires may not conform to the PFA in the GIS datalayer due to considerations such as the safety of fire personnel, successful containment of prescribed fire, experience from previous prescribed fires, etc. This does not mean that vegetation community types not adapted to fire (beech-maple in mesic hollows for example) will be made to burn because they are within the fire line. In most cases, the fire will be allowed to extend into these community types to the degree it would naturally spread from the community type for which fire has been prescribed.

High priority PFAs for application of prescribed fire include S7C&D, and S10B&E due to the presence of prairie species, which are being encroached upon by woody vegetation. The chestnut oak stand in N4A being invaded by beech is a high priority on the north side of Green River, and N6A,B&C are matched with S2A&B plus S10C respectively for comparative fire ecology on either side of Green River. S8D should also rate high because it contains the only karst valley site that was not profoundly disturbed

In the northwest quadrant of the park, FMUs N1-N5 have the most and largest surface streams (least karst), and the most rugged terrain. Exposed limestone is limited to the Glen Dean and Haney members interleaved with sandstone which form the caprock over the Girkin limestone, which is barely exposed in valley bottoms. The rugged terrain in this area is due to major outcrops of resistant Caseyville sandstone, and has been considered part of the Western Coal Field or the Shawnee Hills depending upon the classifier. The border between this quadrant and the balance of the park on the Mammoth Cave Plateau was formerly mapped in a vague way as the Pottsville Escarpment, but is not anymore since there is no escarpment. Keeping this geographic history in mind, there are 10 PFAs in the northwest quadrant, of which half (N1A, N4A, N5A, C, and D) are on sandstone substrates only. These FMAs have Acid Mesic to Xeric habitats with minor cultural disturbance histories. Vegetation in these PFAs is mesic to xeric oak forest/savanna with a strong chestnut oak component, and N1A has a xeric pine stand on the crest of Whistle Mountain as well.

Four PFAs (N2A, N3A, N5E, N5F) are on mixed sandstone (majority) and limestone substrates. Habitat types range from Calcareous Mesic to Acid Xeric with insignificant evidence of disturbance, a reflection of rough terrain with little agricultural use. Both N2A and N3A have a xeric pine stand on sandstone cliff edges. Most pine stands in the park are disturbance related, but these pines are in habitat where they prevail over the long term (source populations). The single PFA in the northwest quadrant based primarily on limestone (Glen Dean) is N5B. The Calcareous Sub-Xeric habitat in N5B supports a reasonably mature oak-hickory forest with little disturbance history. In the absence of fire, all of these communities are being invaded by more mesic species such as beech; the chestnut oak stand in N4A is an outstanding example of this ecological restoration need.

The northeast quadrant of the park is composed of FMUs N6-N9, which contain a half-dozen PFAs (N6A-N9A). The FMUs in this quadrant have moderate topography typical of the Mammoth Cave Plateau with significant karst development in both the Haney and Girkin Limestones. Three PFAs (N6A&B, N9A) are on mixed sandstone (majority) and limestone substrates. Except for N6A which Ellsworth mapped as partly restocking in the mid 1930s, all have minimal disturbance history, and a mix of habitats ranging from Supra-Mesic to Sub-Xeric. The drier habitat types dominate, and moist types are included only to keep the PFA boundary topographically reasonable. Major vegetation cover ranges from mesic oak-hickory forest to sub-xeric chestnut oak forest.

The other three PFAs (N6C, N7A, N8A) are on mixed limestone (majority) and sandstone substrates. Historical disturbance is absent except for part of N8A which was included in order to take advantage of an old road as part of the fire line. All three PFAs contain steep exposures of limestone (Girkin) with Calcareous Sub-Xeric and Xeric habitat which supports cedar-oak savannas, and Acid Sub-Xeric to Mesic zones above with oak forest/savanna. All of these stands in the northeast quadrant are becoming increasingly mesic due to infiltration of sugar maple and beech, and in the case of N6A the

presence of white oak in prime chestnut oak habitat. The goal of prescribed fire in these PFAs is to eliminate the infiltrating mesic tree species.

In the southwest quadrant of the park, FMUs S1 and S2 have generally moderate topography typical of the Mammoth Cave Plateau, but punctuated with sandstone knobs. Karst in the uplands is developed in the alternating caprock limestone and sandstone beds yielding segmented streams which have generally low discharge due to small drainage areas. Karst drainage in the underlying thick limestone (Girkin) beds is in an early stage of development low in the landscape, and therefore of little significance to fire propagation in this part of the park. There are six PFAs in this quadrant, four of which (S1A-D) are entirely on sandstone (Caseyville) prominences, and those in S2 have peripheral exposures of Glen Dean limestone around sandstone knobs. Fire relevant habitats range from Acid Mesic to Calcareous Sub-Xeric, with mature stands limited primarily to rugged sandstone knobs. Vegetation in PFAs S1A and S2A&B is typified by mature chestnut oak being variously invaded by maple and beech; S1C is characterized by mature sub-xeric cedar-oak savanna near the edge of a south slope, and more mesic oak-hickory forest away from the edge. As before, these communities are being invaded by beech and maple, which can be corrected with restoration of fire. FMAs S1B&D plus the limestone habitat surrounding S2A&B are all old fields with mixed coniferous/deciduous forest in mid succession

In the southeast quadrant of the park, FMUs S3-S11 contain the most highly developed karst landscape, and therefore the least surface streams. Surface water is limited to short runs from springs in the caprock limestones, and isolated wetlands. The highly dissected Mammoth Cave Plateau produces generally moderate terrain except for the slope margins of the plateau fragments. Large karst valleys and the underlying extensive cave systems are the main distinguishing characteristics for this portion of the park. There are 27 PFAs in the southeast quadrant with a broad range of habitat types, disturbance histories, and therefore vegetation types.

Seven PFAs are on limestone substrates only. Of these, S7C&D are recently abandoned fields with the greatest concentration of prairie species in the park including the federally threatened Eggert's Sunflower; the reintroduction of fire will eliminate encroaching woody vegetation. Others, including S8A&D plus S11B, contain older abandoned fields supporting successional coniferous and mixed forests; cautious application of fire here will accelerate succession by reducing the presence of fire intolerant pioneer species. Older oak-hickory forest and cedar-oak glades are found in S8C and S9A respectively. The oak-hickory forest of S8C is on Glen Dean limestone found up on the flats of Flint Ridge whereas the cedar-oak glade is on a southwest-facing slope, which mostly accounts for the difference in community type. The management goal for S8C is fuel reduction to enhance the fire break effectiveness of Flint Ridge Road, and to reduce encroachment by mesic species which is also the case for S9A.

Five PFAs are on mixed limestone (majority) and sandstone substrates. Two of these, S3A and S10B, have the Haney limestone caprock component, and incorporate old fields with mixed successional forest. In both cases, these old fields have significant pockets with prairie species, and prescribed fire will help maintain or increase open savanna community type. Given the nature of the fuels, great care will be exercised especially at S10B, which is a historic home site. At FMAs S5A, S10C, and S11C, Girkin limestone slopes with sunny aspects harbor cedar-oak savannas with mesic oak-hickory on the sandstone above. The role of fire applied in these PFAs will be to reduce the growth of fire-intolerant beech and maple.

On mixed sandstone (majority) and limestone substrates, 13 PFAs have been selected. Of these, S5F, S7B, S10A, and S11A have significant old field components with mixed successional vegetation. These old fields have large open spaces with some prairie species, and prescribed fire will maintain open canopy conditions. The remaining nine PFAs in this group (S4A-D, S5B, S5C, S7A, S8B, and S11A) all have reasonably mature oak-hickory forest on the sandstone, and most have limestone (Girkin) slopes with southerly aspects that reach to the floor of karst valleys (for S8B, such slopes are nearby). These dry Calcareous Sub-Xeric habitats are capable of carrying fire up to the Acid Sub-Xeric bands above on the plateau margin, and prevailing seasonal winds from the south would carry fire into adjacent Acid Mesic habitats. Though we do not yet know with certainty where savanna would have prevailed on the major ridges (plateau fragments) in this quadrant, these southerly ridge margins with adjacent sub-xeric slopes have the highest probability of supporting this eco-type. The southern edge of Jim Lee Ridge (in S4C), with its dominant post and blackjack oak, stands as an excellent oak savanna remnant. The role of fire in these nine FMAs will be to perpetuate the forest-prairie hybrid of savanna, reduce encroachment by mesic species, and in S8B reduce

fuel to enhance the fire break effectiveness of Flint Ridge Road.

There are only two PFAs in this quadrant that are exclusively on sandstone (S5D S5E), and both are adjacent to the southern boundary of the park. One (S5D) has largely successional mixed forest typical of old fields, and the other has reasonably mature oak-hickory forest. The primary goal of prescribed fire in these PFAs is fuel reduction to retard or stop propagation of a wildfire entering from outside the park. More of these fire break PFAs may be justified along the southern park border at a later time. The juxtaposition of these two PFAs provides an excellent fire ecology research opportunity due to their differing successional status.

6.2 Historical Weather Analysis

Cumulative data on wind (1973-91), temperature (1961-1990), and precipitation (1961-1990) have been compiled for nearby Bowling Green, Kentucky by the Kentucky Climate Center at Western Kentucky University. Monthly summaries indicate that southerly winds prevail during both the spring and fall fire seasons (see Appendix 5). Average monthly temperatures range from 77.9 F in July to 32.9 F in January with means for March, April, September, and October at 47.4, 57.0, 69.7, and 57.8 degrees F respectively. Warmer summer months have generally low fire potential due to growing vegetation, and high humidity; winter months are generally too cool for fuels to dry well. Average monthly precipitation ranges from 5.10 inches in March to 3.02 inches in October. April and September means stand at 4.32 and 3.72 inches of rainfall respectively.

Of the two frequently used drought indices, the Keetch-Byram Drought Index (KDBI) is the most appropriate drought index for the Park. The KDBI is a mathematically calculated drought indicator relating to the amount of moisture in the top seven inches of soil or duff/soil. It is based on the ambient air temperature and recent precipitation in relation to the mean annual rainfall for a specific weather station. The range of the KDBI is 0-800, with 0 being saturated and 800 being maximum drought. The highest KDBI reading for the geographical area in 1999 was 767, recorded in September 1999. The KBDI can be obtained from the Kentucky Interagency Coordination Center (KICC)or found on their website, *www.r8web/boonefire*.

6.3 Fire Seasons, Fuel Characteristics, and Fire Behavior

There are two fire seasons in the Mammoth Cave area, one in spring from February 15th to April 30th and the other in fall from October 1st to December 15th. Given that many herbaceous plants remain alive and even bloom into late October (Seymour 1997), fuels are not as consistently dry in fall as in the spring, and leaves do not typically finish dropping until late October. Approximately 45% of the park is land that was cleared for agricultural purposes, including row crops and pasture. These old fields are now in early to mid succession, and depending upon the habitat type range from low to high inflammability. Forest stands in some old fields on Floodplain Alluvium habitat have progressed through secondary succession rapidly, and have little fire potential. On the other hand, dense stands of successional eastern red cedar and Virginia pine in Calcareous Sub-Xeric habitat within the large karst valleys, and Mesic to Subxeric habitats on the uplands, could sustain significant fire behavior under the right conditions.

Fuel types in the park have been classified according to the National Fire Danger Rating System (NFDRS) and the Northern Forest Fire laboratory Fire Behavior Prediction System fuel modeling system (FBPS) (Deeming et al 1978:30, Anderson 1982). These are summarized in Tables 3 and 4 on the following pages and will be discussed in order from most to least fire prone.

Small, mostly open fields supporting native prairie species exist in the park. These areas cannot be regarded as prairie remnants since we do not yet know pre-settlement vegetation patterns in detail, but they are important refuges for species with almost no remaining habitat (PFAs S7C&D are examples - see Figure 3). These areas most closely match NFDRS Fuel Model L and FBPS Fuel Model 1. During spring especially, the standing dead grasses and forbs present are light fuels, which dry quickly following rain and can burn very rapidly when ignited.

Many stands of successional cedar-pine in the cores of old fields (Xeric-Mesic Coniferous Forest in Figure 3) are best categorized as NFDRS Fuel Model Q and FBPS Fuel Model 6. These stands are dense, but have a patchwork of more open savanna with highly flammable grasses and forbs. In dense areas, the forest floor is covered in moss and lichens with some needle litter and small branches. Dead low branches persist on trees providing ladder fuels for potential crown fire. Surface fires would be typically slow, but under windy conditions, crown fire could result.

In dense, successional conifer stands in the park (especially virginia pine), with heavy accumulations of branches and downed trees from ice storms and wind throw, NFDRS Fuel Model

G and FBPS Fuel Model 10 apply. The canopy openings created support grassy and herbaceous light fuels which in combination with the heavy dead branches and trunks could produce a very intense fire posing control difficulties.

On sunny steep limestone slopes, apparently virgin cedar/oak glades are found. The exposed bedrock benches with thinly scattered fuel generally results in low fire frequency and severity most consistent with NFDRS Fuel Model C and FBPS Fuel Model 9. Fuel in cedar-oak glades consists of sparse leaf and needle litter interspersed with thin patches of grass and forbs. Bedrock exposures interrupt fuel continuity, and natural soil piping through the limestone results in thin soil where present. Fire Behavior in this fuel type will be greatly influenced by the discontinuity of fuels.

Most of the Virginia pine in the park is successional growth in old fields. However, dry sandstone cliff margins of Acid Xeric habitat type support mature Virginia pine stands. Other than lowbush blueberries, there is little undergrowth, and the compact litter of needles is best represented by NFDRS Fuel Model H and FBPS Fuel Model 8. Fires are typically slow and confined to the surface except under unusually hot, dry, and windy conditions.

After leaf fall and before emergence of spring growth, four vegetation types fit Fuel Model E and FBPS Fuel Model 9. These are forest/savanna of the xeric-subxeric deciduous, upland mesic deciduous, and mixed deciduous-coniferous types, plus the mesic slope deciduous forest (see Figure 3 for distributions). Hardwood leaf litter of mesic oak-hickory forest is the basis for this fuel type along with mixed hardwood conifer types where hardwoods account for more than half the overstory. In sunny, dry habitats that fit NFDRS Fuel Model E, the thicker leaves of trees adapted to these xeric and sub-xeric sites, such as blackjack, post, chinkapin, and chestnut oaks, do not readily mat down or deteriorate. Therefore these leaves dry quicker, and the air spaces between leaves make this litter (and any other "fluffy" fuel) more flammable (Deeming et al 1978:8). Along the margins of old fields there are mixed deciduous and coniferous stands. With the exception of red maple, the tulip poplar, dogwood, and sweetgum trees interspersed with eastern red cedar and Virginia pine produce litter of average flammability. However, the frequent association of this vegetation type with more flammable successional cedar-pine dominated stands in the cores of old fields should also be taken into consideration. At the moist end of the Fuel Model E spectrum is leaf litter produced by the mesic slope/floodplain deciduous forest. These habitats are less exposed to sun than the drier sites, and are typified by sugar and silver maple, beech, box elder, and sycamore. Maple leaves especially mat down after rain and decay quickly, which, along with habitat-related cooler temperatures and lower evaporation rates, makes ignition less likely. Fires in deciduous leaf litter are typically confined to the surface. Rates of spread are usually slow, but on windy days, fire can move faster than predicted due to windblown leaves.

Once the trees have leafed out, all of these savanna and forest types are classified as Fuel Model R and FBPS Fuel Model 8, which have a low probability of ignition except under extreme drought conditions. However, during such extremely dry periods these deciduous forest stands can develop rapid fires on drought prone sub-xeric slopes.

Table 3 below demonstrates anticipated fire behavior under "average" and "extreme" conditions and critical threshold values effecting fire controllability. The values were calculated using the BEHAVE (Andrews 1986). Fire behavior prediction model using weather inputs from the Park NFDRS Weather station (15601). The weather data used cover the 10-year period from 1989-1999 and the weather indices were calculated using the Fire Family Plus (Bradshaw 1999) software package. It should be recognized that table values are based on models rather than on direct observation of fire behavior in these fuel types. As Park Managers have the opportunity to observe and monitor fire behavior, these values may be refined, and the model calibrated to better reflect local fuel and weather conditions.

Table 4 below outlines potential critical weather parameters that would result in fire behavior exceeding initial attack capabilities (flames lengths greater than 8 feet). These values were calculated using the RX Window Module of the BEHAVE program (Andrews 1986). Such values are useful both for facilitating recognition of potential extreme fire behavior conditions, as well as for assisting in prescription development for the prescribed fire program. It should be noted that generally 2 or 3 weather parameters must all be aligned in order for extreme conditions to result. It should also be noted that these are modeled values and should serve only as guidelines. Additionally, values have not been included for certain parameters such as live fuel moisture and 1000 hour fuel moisture as there has been little opportunity to date to observe fire behavior and

Table 3. Potential Fire Behavior Under Average and Extreme Conditions

NFDRS Model	FBPS Fuel	Fuel Type/Vegetation	Fire Behavior Average Conditions		Fire Behavior Extreme Conditions	
			Flame Length (Feet)	*Rate of Spread* (Chains/hr)	*Flame Length* (Feet)	*Rate of Spread* (Chains/hr)
L	1	Prairie grasses in old fields	3	65	8**	270
Q	6	Cedar/Pine in Old Fields	6	34	13**	180
G	10	Dead pines from ice storms & wind	6	12	13**	61
C	9	Cedar-oak glades	3	9	8**	72
E	9	Hardwood leaf litter	3	9	8**	72
R	8	Hardwood litter	1	2	2	5

***Exceeds direct attack capabilities = Flame lengths greater than 8 feet, indirect attack required*
Average conditions = 1989-2000 NFRDRS station 156501 mean fire season weather conditions

associated weather in certain unique vegetation types. As the opportunity arises, fire monitoring data collection on both wildland fires and prescribed fires will facilitate refinement of these values as well as development of critical values for additional parameters. Lastly, it should be note that while the values listed will potentially result in flame lengths greater than 8 feet, this does not imply sustained uncontrollable wildfire. They simply imply that direct attack is not a safe tactic. Additionally, these conditions, especially wind speed, may vary greatly in a short time period, and are fleeting in nature.

7.1 Prescribed Fire

The object of prescribed fire is to safely restore forest, savanna, and prairie ecosystems that have been distorted or reduced in the park by fire suppression, and to reduce excessive or hazard fuel accumulations also resulting from fire suppression. Prescribed fire is needed to restore and maintain habitat for marginalized ecosystems, which include state and federally threatened or endangered species, because pre-settlement sources of fire no longer exist. Native American populations are long gone, and lightning has little chance of creating significant fires under the closed canopy conditions created by fire suppression. Prescribed fire is a tool, which can reduce the potentially catastrophic consequences of wildland fires in excessive or hazard fuel accumulations. Used in conjunction with mechanical treatments when necessary, fire can

Table 4. Critical Weather Parameters resulting in Need for Indirect Attack

NFDRS Model	FBPS Model	FuelType/Vegetation	Moisture of Extinction	Critical Weather Parameters Resulting in Fire Behavior Exceeding Direct Attack Capabilities
L	1	Prairie grasses in old fields	12	1 hour fuel moisture < 7% AND Windspeed >15 MPH
Q	6	Cedar/Pine in old fields	25	Live Fuel Moisture Windspeed
G	10	Dead pines from ice storms & wind	25	1000 hr fuel moisture Windspeed
C	9	Cedar-oak glades	15	1 hour fuel moisture < 7% AND Windspeed > 15 mph
E	9	Hardwood leaf litter	25	1 hour fuel moisture AND Windspeed > 15 mph

help restore the full range of ecological benefits of fire without compromising other resources. Management objectives for Prescribed Fire Areas are discussed in section 6.1.

7.2 Fire Suppression

All wildland fires will be suppressed using the appropriate management response. The appropriate management response will vary from fire to fire and sometimes even along the perimeter of a fire. Appropriate management response options range from monitoring with minimal on-the-ground disturbance to intense suppression actions on all perimeters of the fire. The appropriate management response is developed from analysis of local situations. Factors such as values to be protected, management objectives, external concerns, and land use need to be formally assessed. The first priority in all fire suppression operations is safety.

7.3 Fire Management Units

Physical geography of the Fire Management Units (FMU) was introduced by quadrant in section 6.1 along with habitat types and vegetation cover for Fire Management Areas where prescribed fire is planned. All FMUs are displayed on maps in Figures 2, 3, and 4. To the greatest extent possible, each FMU is designed as a defensible polygon in the event of wildfire. Boundaries consist of rivers, ravines, and roads within the park, and the park boundary around the outer perimeter. As stated in section 5.2, any wildland fire within and adjacent to park boundaries will be suppressed using all appropriate means necessary according to the judgement of the park superintendent. This includes unplanned ignitions within designated Prescribed Fire Areas. Access, habitat types, vegetation, fuel types, expected fire behavior and effects, and values to be protected relevant to suppression of wildland fire in FMUs will be considered by quadrant to facilitate discussion. GIS-based data on FMUs are compiled in Appendix 3. Obviously, the park perimeter is adjoined by private property, which contains valuable fields, timber, and structures. This real property is not enumerated here, but will be protected in cooperation with area Fire Departments. This boundary buffer is essentially a single Fire Management Unit (see figure 4).

Access to FMUs N1-N5 in the northwest quadrant of the park is made difficult due to large surface streams, and rugged terrain. Unit N1 (Whistle Mountain) north of Bylew Creek can be most directly accessed via private roads off KY 728; N2 (Nolin West) can be reached from Poplar Springs Church Road, Woodside Road, and private lanes; N3 (Nolin East) is off Ollie Ridge Road, and Second Creek Fire Tower Road; N4 (First Creek) is separated from N5 (Buffalo Creek) by Houchins Ferry Road. The rest of N5 can be reached via Collie Ridge Trail, which is an old road.

The rugged terrain in this quadrant is due to thick outcrops of Caseyville sandstone, and limestone exposure is very limited. Consequently, Acid Mesic to Xeric habitats with minor cultural disturbance histories dominate. Vegetation in the fire prone portions of these FMUs is mesic to xeric oak forest/savanna with a strong chestnut oak component, and there are xeric pine stands on the edges of sandstone cliffs as well.

Hazards for firefighters include cliffs, very steep terrain, and long response times for assistance. Safety zones consist of the Green and Nolin Rivers, tributary streams, hemlock hollows, roads, and cemeteries. Real property to protect includes the Great Onyx Job Corps Center, 11 cemeteries, and 2 trailheads.

Access to FMUs N6-N9 in the northeast quadrant is relatively straight forward as the North Entrance Road separates N6 (Turnhole Bend) and N7 (Big Hollow). The more expansive Turnhole Bend Unit also has Maple Springs Loop, Buffalo Trail (an old road), the road to Good Springs Church, and Bailey Road. The north side of the Big Hollow Unit, and N8 (Goblin Knob) are reached from Little Jordan Road. White Oak Trail (an old road) separates the Goblin Knob Unit from N9 (Big Woods), which can be reached by either Little Jordan Road or Dennison Ferry Road. Except for White Oak Trail and the Hickory Cabin road, old pre-park roads have not been kept open in the northeast quadrant. However, many of the old roadbeds in the park can be made accessible for four-wheel drive vehicles by trimming brush and clearing deadfall.

This quadrant is part of the Mammoth Cave Plateau, which has largely moderate terrain with significant karst development in both the Haney and Girkin Limestones. Mixed sandstone and limestone substrates produced by weathering of the caprock sequence cover most of the plateau

surface. Consequently, Acid Mesic and Calcareous Sub-Xeric habitats with significant cultural disturbance histories dominate. Vegetation in the portions of these FMUs capable of carrying fire is mostly mesic coniferous and mixed forest in former fields. In less disturbed areas, mesic oak-hickory forest and sub-xeric oak forest/savanna are found.

Hazards for firefighters include cliffs and steep bluffs along Green River, and the pit entrance to Wilson Cave. Safety zones consist of the Green River, small headwater streams, dry streambeds, roads, and cemeteries. Real property to protect includes Good Spring Church, Maple Springs Research Center and Group Camp, 17 cemeteries, and 3 trailheads. Hibernation colonies of Indiana Bats, listed as endangered with U.S. Fish and Wildlife Service, are present in Wilson and Bat Caves from September through April. Given that the cave inhales on winter days, smoke in the area could have serious consequences. Priority suppression of wildland fire is advisable in the vicinity of these caves unless the surface temperature is at or above 56 F.

Access to FMUs S1 (Indian Hill) and S2 (Crumps Knob) in the southwest quadrant is possible off KY 70. Houchins Ferry Road cuts across the Indian Hill Unit, and an unmarked road leads to James Cemetery. Brooks Knob Fire Tower Road leads to Crumps and Brooks Knobs in S2, and can be used by four-wheel drive vehicles almost to Green River. The Leon Raymer Road (AKA Cedar Lane) also offers access to the head of Poteet Hollow.

FMUs S1 and S2 have generally moderate topography typical of the Mammoth Cave Plateau, but punctuated with Caseyville Sandstone knobs. Karst development is limited in this quadrant since the major cave-bearing limestones are barely above the level of Green River. Fire relevant habitats are primarily Acid Mesic and Calcareous Sub-Xeric, with significant historic disturbance. Most level areas were fields or pasture, which are now occupied by mesic coniferous and mixed forest. Mature stands capable of carrying fire are limited primarily to rugged sandstone knobs where mesic oak-hickory forest and sub-xeric oak forest/savanna are found.

Hazards for firefighters include cliffs, steep bluffs, and oil wells adjacent to the park. Safety zones consist of the Green River, small headwater streams, dry streambeds, roads, and cemeteries. Real property to protect includes Houchins Ferry and Campground, plus four cemeteries.

FMUs in the southeast quadrant are reasonably accessible because of a relatively extensive road system. In order for the following description to make sense, it will be necessary to refer to Figure 4. The Joppa Ridge Road is a divider between S3 (Joppa Ridge) and S4 (Jim Lee), and the West Entrance Road separates these two from S5 (Woolsey Valley) to the south. The Woolsey Valley Unit is also bounded on the south by Cedar Hill Church Road, and Old Mexico Road cuts through the southern edge of this unit; a side spur to France Cemetery could be driven into Woolsey Valley if deadfall were cleared. The Jim Lee Unit is bounded on the east by the South Entrance Road, which divides it from S7 (Doyel Valley), and S9 (Mammoth). A short spur to the Carmichael and Violet City Entrances also serves the Jim Lee Unit, and an old road across the ridge could be driven if deadfall were cleared. The Doyel Valley Unit is divided from Woolsey Valley by the South Entrance Road, and from S8 (Houchins Valley) by the East Entrance Road; this latter unit is also served by the Union City Road, Wondering Woods Road, the road to Frozen Niagara Entrance, and the road to Mt. McKinley pump station. The Houchins Valley Unit is bounded on the east by Park Ridge Road, and separated from S10 (Flint Ridge) by Flint Ridge Road; this latter unit is also served by the Great Onyx Cave Road, and Crystal Cave Road. Dennison Ferry Road divides the Flint Ridge Unit from S11 (Dennison Ferry), and this latter unit is bisected by Lick Log Road. Access to S6 (Parkway) is self-explanatory.

FMUs S3-S11 contain the most highly developed karst landscape, and therefore the least surface streams. Surface water is limited to isolated wetlands and short runs from springs in the caprock limestones. The Mammoth Cave Plateau in this quadrant has moderate terrain except for the slope margins of plateau fragments or ridges. Large karst valleys distinguish this portion of the park from all others, and produce extensive Calcareous Sub-Xeric to Xeric Habitats. Shaded valley walls yield Calcareous Mesic Habitats which, with the prevailing southerly winds, should serve as fuel breaks. The ridge tops are generally (but not always) sandstone based, and have extensive Acid Mesic habitats with some smaller but botanically significant Sub-Xeric sites as well. Most level sites in both valleys and uplands were used for agriculture, and were therefore significantly disturbed. These fields and pastures are now occupied by mesic coniferous and mixed forest. Reasonably mature stands capable of carrying fire are very limited except for the Mammoth Cave Estate where mesic oak-hickory forest is especially abundant, and sub-xeric cedar-oak savanna is also found.

Hazards for firefighters include cliffs, and steep bluffs. Safety zones consist of the Green River, small spring runs, roads, and cemeteries. Real property to protect includes the Headquarters Area Developments (Visitor Center, Hotel, Post Office, Gas Station, Campground, Residential Area, Maintenance Area, etc.), two historic churches, and 35 cemeteries. As well, the park Air Quality Monitoring Station is located just beyond the southern boundary. Long, Colossal, and Dixon Caves have hibernating colonies of Indiana and Gray Bats, which are listed as endangered with U.S. Fish and Wildlife Service. Indiana Bats have also recently been sighted in the Historic Entrance of Mammoth Cave, and all populations remain from September through April. On this basis alone, direct suppression of fire is advisable in the vicinity of these caves to prevent inhalation of smoke by both caves (and therefore bats) unless the surface temperature is at or above 50 F. The Constant Temperature Zone in caves of the Mammoth Cave area is 56-57 F, and lower elevation entrances begin to inhale air significantly when surface temperatures dip below 50F (Jernigan 1997).

7.4 Annual Fire Weather Cycles

The annual fire weather cycle is more a function of growing season and temperature than precipitation. Average precipitation is relatively constant throughout the seasons. Warm temperatures and dormant vegetation conditions in the spring and fall condition the fuels for easy ignition. In contrast, during the winter, cold temperatures prolong the wetting effect of the precipitation, and in the summer, the green condition of the foliage (coupled with the usual higher humidity) makes for poor ignition conditions under normal circumstances.

As a result of the above weather cycles, there are two fire seasons in the Mammoth Cave area, one in spring from February 15th to April 30th and the other in fall from October 1st to December 15th. Normal extremes during this time consist of a few days in the very high to extreme categories. Fires occurring on these can be expected to spread rapidly and burn with high intensity. Depending on fuel type, spotting and crowning can occur. More than likely an indirect attack would be necessary. The use of aerial attack is warranted when structures are at risk.

Exceptions to the norm have occurred. Atypical dry periods in any season can result in more fires and/or unusually higher fire intensities. For example, in 1999, an extremely dry summer made the normally fireproof hardwood forest burnable. Numerous human-caused fires near the park and in the state burned hundreds of acres with high intensity. Statewide burning bans, campfire bans in the park, and daily detection flights by state forestry aircraft were initiated.

Unless there is an unusual amount of snow on the ground, atypical warm temperatures in February will condition fuels so that they are highly flammable. This type of event occurs frequently. Out of the eighteen total fires for a total of 324 acres for the ten-year period, only three of these fires occurred in February and burned a total of 0.7 acres. Although this is a small number, thousands of acres under state jurisdiction burn during this time.

8.1 Staff Responsibilities

The park fire organization requires the participation of many employees to safely accomplish fire management goals. It is important that an interdivisional approach be used so that all aspects of the program are addressed. This plan identifies the positions involved in conducting an effective fire management program.

All suppression program activities are to be conducted in accordance with Service policy prescribed in DO #18 and RM-18 (*http://fire.nifc.nps.gov/fire/fmpc/policy.htm*). Copies of these policies are available in the administration building, the science/resource management office, and the ranger station. It is suggested that all personnel involved in wildland fire suppression activities become familiar with these guidelines and the fire management plan.

Superintendent and Deputy Superintendent

- Responsible for the overall management of the Park including the fire management program.

8.0 Fire Management Organization and Responsibilities

- Responsible for assuring employees meet identified qualification standards related to fire suppression.
- Ensures that trained and certified employees are made available to participate in wildland fire activities, as the situation demands, and that employees with operational, administrative, or other skills support the wildland fire program as necessary.
- Responsible for final approval of all prescribed fire plans.
- Responsible for periodic assessment signature to certify that continued management of wildland fire use actions is acceptable. Under certain conditions may delegate this responsibility to another organization level.
- Works to ensure effective cooperative relations between the Park, cooperating fire organizations, and adjoining landowners.
- Approves any use of mechanized equipment within the Park.
- Appoints Agency Administrator's representative
- Supports the national wildland fire needs, as resources are available, given other critical needs that may exist in the park.

Division Chiefs

- Support the fire management program
- Ensures that qualified personnel are available for training and work capacity testing to maintain a minimum Park fire roster.
- Adjusts schedules during fire seasons so that overhead and firefighters are available for duty.
- Provides equipment and personnel for special fire-related projects, i.e., media relations, fire suppression, logistical support, overhead teams, etc.

Chief of Science and Resources Management

- Coordinates updates of the fire management plan.
- Manages the prescribed fire program components related to monitoring, planning and research.
- Reviews all purchases and obligations made or proposed for prescribed fire accounts.
- Serves as chair of the Prescribed Fire Committee; presents recommendations related to the Annual Prescribed Fire/Hazard Fuel Reduction Plan to the Superintendent for review.
- Serves as Resource Advisor during wildland fire suppression operations.
- Briefs the Superintendent, Deputy Superintendent on current prescribed fire management activity.
- Consults with Superintendent on any fire-related research proposals or recommendations.
- Assists FMO with completion of Wildland Fire Situation Analysis (WFSA).

Chief Park Ranger

- Manages the park's wildland fire suppression and prescribed fire control operations.
- Advises Superintendent and Deputy Superintendent of emergency fire situations and potential.
- Monitors events during suppression activities, and is authorized to intercede, to insure the safety of fire line personnel.
- Serves as a member of the Prescribed Fire Planning Committee.
- Ensures that identified individuals within the park are prepared and qualified to perform suppression duties.
- Responsible for public safety (evacuations, traffic control, etc.) during wildland fire and prescribed fire incidents.

- Responsible for criminal investigation of suspected arson fires.
- Recommends to the Superintendent, and enforces area closures related to fire use restrictions when fire danger reaches critical levels.
- Reviews all purchases and obligations made or proposed for fire suppression accounts.
- Reviews obligations made or proposed for emergency preparedness.
- Assists Fire Management Officer during completion of WFSA.
- Reviews prescribed fire burn plans.

Fire Management Officer (FMO)(Ranger Activities Division)

- Implements the operational aspects of the Fire Management Plan, including fire prevention, wildland fire suppression, prescribed fire operations, aviation, dispatching and mobilization.
- Ensures that the fire management program is safely coordinated and directed within Service guidelines as defined in RM-18 and DO-18.
- Represents the park and coordinates fire-related activities with other Service areas, regional and national fire staff, and local, state, and Federal fire organizations
- Compiles the Hazard Fuel Reduction Plan.
- Prepares and submits annual normal year FIREPRO budget, and approves expenditures for emergency preparedness, suppression, and prescribed fire activities.
- Maintains training and qualification records for park personnel, assesses staffing needs, recommends staff development to meet interagency and prescribed fire needs, administers the work capacity testing program, coordinates the training program, updates individual fire qualification records, prepares Red-cards and recommends individual qualifications for approval by the Chief Ranger.
- Works with GIS Specialist to maintain historical fire occurrences (RX and wildland fire).
- Coordinates mobilization of park resources for in-park and out-of-park assignments. Assigns Type IV or Type V Incident Commanders for wildland fire suppression operations and Prescribed Burn Bosses for prescribed fire activities.
- Maintains and oversees all fire caches and equipment.
- Completes the WFSA for superintendent when fire escapes initial attack or a prescribed fire escapes the burn unit.
- Designates the Incident Safety Officer during wildland and prescribed fire suppression actions.
- Develops a staffing plan to reflect park suppression staffing needs.
- Works closely with the Park's structural fire coordinator to ensure that maximum efficiency is achieved in situations where structural units can provide assistance.
- Coordinates with applicable supervisors the staffing and funding of red-carded personnel during periods of severity.
- Oversees fire weather station operation and data entry. Completes and enter Individual Fire Reports (DI-1202) and daily situation reports into Shared Applications Computer System (SACS). Calculates Fire Danger utilizing the National Fire Danger Rating System (NFDRS) and Weather Information Management System (WIMS).
- Serves as a member of the Prescribed Fire Planning Committee.
- Prepares or reviews individual prescribed fire plans
- Coordinates the use of air attack resources on all wildland fires occurring within the park
- Serves as Agency Administrator Representative, when assigned, and drafts the Limited Delegation of Authority and briefing statement for approval by the Superintendent
- Maintains qualifications as a wildland firefighter
- Serves as point of contact for Fire Use Modules
- Coordinates updates of operations sections of the Fire Management Plan

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Park Ecologist

- Coordinates the fire effects monitoring program and is responsible for evaluating effects on federally protected species before and after prescribed burns and following wildland fires.
- Prioritizes prescribed fire needs and presents to the prescribed fire committee.
- Develops prescribed fire budget request in FIREPRO
- Works with the Chief of Interpretation and Visitor Services on ecological aspects of fire for interpretive and environmental education programs.
- Works with GIS specialist to maintain vegetation datalayers, habitat models, and burn area records.
- Prepares or reviews fire research proposals, and coordinates the completion of fire research.
- Inspects suppression sites upon request, and assists with the development of rehabilitation plans.
- Serves as a member of the Prescribed Fire Planning Committee.
- Assists FMO during completion of WFSA.
- Coordinates updates of ecologically relevant sections in the Fire Management Plan.

GIS Specialist

- Works with ecologist to maintain vegetation datalayers, habitat models, and prescribed fire area boundaries
- Works with FMO to maintain the fire history datalayer

Data Manager

- Works with ecologist to maintain databases and metadata on vegetation, habitat models, and prescribed fire area boundaries
- Works with FMO to maintain the database and metadata on fire history

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Cultural Resource Specialist

- Inspects suppression sites upon request, and assists with the development of rehabilitation plans.
- May serve as a member of the Prescribed Fire Planning Committee.
- May assist FMO with completion of WFSA.

Air Quality Specialist

- Reviews annual/seasonal prescribed fire plans and reports on air quality monitoring to assure air quality objectives are achieved. Monitors fire effects on air quality.

Park Hydrologist

- Reviews annual/seasonal prescribed fire plans and reports on water quality monitoring to assure water quality objectives are achieved. Monitors fire effects on water quality.

Occupational Safety and Health Officer

- Reviews prescribed and wildland fire safety plans.
- Serves as a member of prescribed fire committee.

Incident Safety Officer

- Establishes systems to monitor fire activities for hazards and risks. Takes appropriate preventative action.
- Establishes operating procedures for safety assistants.
- Evaluates operating procedures. Updates or modifies procedures to meet the safety needs on the fire.
- Participates in planning meetings.
- Reviews and approves the Incident Medical Plan.
- Prepares the safety message included in the Incident Action Plan
- Presents safety briefing to overhead.

- Prepares accident reports upon request of the Incident Commander.
- Ensures accidents are investigated.
- Prepares final safety report.

Chief of Interpretation and Visitor Services

- Develops and implements interpretive and environmental education programs on fire management.

Chief of External Programs and Communications

- With PIO develops and coordinates pre-event public information for prescribed fire in cooperation with Interpretation staff.
- Coordinates media coverage of fire management actions.
- Assigns or designates a Public Information Officer(s) and a liaison if needed for prescribed fire and wildland fires.
- Serves on the prescribed fire committee (Chief or PIO).

Administrative Officer

- Tracks expenditures against fire accounts for prescribed fire operations, mechanical fuel treatment projects, and preparedness activities.
- Tracks expenditures for suppression and prescribed fire/hazard fuel reduction projects.
- Reports status of funds/expenditures to the Chief Ranger.
- Prepares a final financial report as an official record

Ranger Station/Detailed Dispatcher

- Broadcasts daily Fire Weather Reports and Fire Danger Indexes.
- Serves as the communication link for wildland fire incidents and with Incident Commanders in the field.
- Receives initial reports of wildland fires from field personnel, fire cooperators, and citizen calls.
- Notifies FMO of the fire report.
- Communicates fire reports and updates to local fire cooperator dispatcher(s)and state coordination center.
- Facilitates dispatch of park and/or cooperator suppression resources (including implementation of standard response procedure if FMO is not available).
- Notifies the FMO promptly of updates on fire activity, weather conditions, and suppression related developments.
- Maintains an incident log and assembles regular situation updates on uncontrolled fires. Appropriate NFES forms will be used.
- On duty dispatcher will request additional dispatch assistance if fire and non-fire radio traffic workload becomes excessive.
- Requests fire program support assistance through the FMO, if needed.

Wildland Fire Incident Commander

- The Incident Commander (IC) will be responsible for the safe and efficient suppression of the assigned wildland fire.
- Fulfill the duties described for the IC in the Field Operations Guidelines (IC-420-1).
- Notify Communications Center of all resource needs and situation updates, including the need for an extended attack.
- Ensure wildland fire behavior is monitored and required data is collected.
- Ensure that personnel are qualified for the job they are performing.
- Identify and protect endangered and threatened species, historic structures, and archaeological sites according to the Fire Management Plan.
- Utilize minimum impact suppression tactics.

- Ensure fire is manned until declared out.
- Ensure that the fire site is fully rehabilitated.
- Submit completed Field Wildland fire report and Time and Cost report to FMO within 5 days of fire being declared out.

Prescribed Burn Boss

- Ensures that all prescribed fire operations are conducted with the utmost regard for safety.
- Write prescribed burn prescriptions for assigned projects.
- Implement prescribed burn plans.
- Assist with the administration, monitoring, and evaluation of prescribed burns.
- Notify FMO of any fire escape from burn unit.

Park Fire Personnel

- The Park fire personnel are responsible for their own fire records, equipment, physical conditioning, and safety.
- Qualifying annually by passing the appropriate work capacity between January 1-31.
- Maintaining assigned fire equipment in ready state and using all safety gear assigned.
- Assisting the FMO in maintaining accurate personal fire training and experience records.

Fire Cooperators (see Table 6 and Appendix 6)

- Provide assistance in detection and suppression of wildland fires.
- Assist, as needed, in the investigation of suspicious fires.

8.2 Firefighter Qualifications

The fire management program currently (2001) does not have qualified individuals on staff to fully implement the fire management program. A listing of fire positions which need to be developed in order to gain the adequate level of self-sufficiency necessary to fully implement the program at the level proposed in this plan can be found in Table 5.

8.3 Interagency Coordination

Agencies cooperating with the Park include the USDA Forest Service, Kentucky Division of Forestry (KDF), Park City Volunteer Fire Department, Cave City Volunteer Fire Department, Lincoln Volunteer Fire Department, Cub Run Volunteer Fire Department, and the National Weather Service (NWS).

The Daniel Boone National Forest Dispatch Office serves as the Kentucky Interagency Coordination Center (KICC) for all interagency resources. This is the primary contact for the Park to request additional fire fighting resources. The Park frequently assigns a Support Dispatcher

Table 5. Minimum Staffing Targets
Note: One firefighter may fill more than one position.

Position	*Wildfire*	*Prescribed Fire*
Incident Commander Type 4 (ICT4)	2	
Incident Commander Type 5 (ICT5)	2	
Engine Boss (ENGB)	2	2
Crew Boss (CRWB)	2	2
Advanced Firefighter/Squad Boss (FFT1)	6	3
Firefighter (FFT2)	15	15
Prescribed Fire Burn Boss Type 2 (RXB2)		2
Ignition Specialist Type 2 (RXI2)		2
RXFM (Fire Monitor)		4
Expanded Dispatch Recorder (EDRC)	2	
Expanded Support Dispatcher (EDSD)	2	
Situation Unit Leader (SITL)	1	
Field Observer (FOBS)	1	1
Training Specialist (TNSP)	1	1
Information Officer Type 3 (IOF3)	1	1
Personnel Time Recorder (PTRC)	2	
Equipment Time Recorder (EQTR)	2	
Supply Unit Leader (SPUL)	1	
Resource Unit Leader (RESL)	1	

to this center. The cooperators of the KICC meet annually to discuss procedures, training needs and share information. The KICC website *(www.r8web.com/boonefire)* serves as a clearinghouse for fire weather forecasts, Weather Information Management System (WIMS) fire danger ratings, daily fire weather reports, and regional and national situation reports.

Currently, the Park does not have qualified staff to fully implement the plan. There are two fire staff shortcomings that can be addressed using the park's cooperators.

• The present staff has an adequate level of experience to manage the majority of the fires occurring on Service lands. However, their level of qualifications does not reflect their level of experience. There is a need to work primarily with personnel from the Daniel Boone National Forest so that performance-based task books can be completed for individuals ready to become Single Resource Boss or Incident Commander qualified.

• The park lacks experienced personnel to implement the prescribed burn program. Burn Bosses and other experienced prescribed fire personnel must be requested to assist the park until its personnel can become qualified.

8.4 Interagency Fitness and Training Standards
In keeping with NWCG guidelines, each agency will meet its own fitness and training standards. All fire suppression forces involved in fire suppression actions on fires occurring on Service lands will meet its own agencies personal protective equipment standards. Proper fitness and training are fundamental to achieving fire management goals safely.

9.1 Wildland Fire Use

Until the park has adequate resources to implement such a program, all wildland fires regardless of origin will be suppressed using the appropriate management response. When this plan is revised in five years, the use of fire to achieve resource management objectives (Wildland Fire Use) will be evaluated. As part of the evaluation process, an environmental assessment will be completed. Pending the outcome of the environmental assessment, the use of fire to achieve management objectives may be instituted. In that event, the Fire Management Plan will be revised, as necessary, to reflect the change.

9.2 Wildland Fire Suppression
All wildland fires will receive initial attack action and be suppressed using the appropriate management response. The appropriate management response will vary from fire to fire and sometimes even along the perimeter of a fire depending on the situation.

It is important to note that the use of the appropriate management response concept dispels the interpretation that there is only one way to respond to each set of circumstances. Appropriate management response options range from monitoring with minimal on-the-ground disturbance,

Table 6. Interagency Contacts

Contact	*Title*	*Phone Number*
KICC	Dispatcher	606-745-3171
KDF	District Forester	502-766-5010
NWS	Fire Weather Forecaster	502-968-5663 800-292-5588
Park City VFD	Cooperator	270-651-3339
Cave City VFD	Cooperator	270-773-2211
Lincoln VFD	Cooperator	270-286-4222
Cub Run VFD	Cooperator	270-524-4567

to aggressive initial attack on all perimeters of the fire, to a combination of strategies to achieve confinement. The Incident Commander will develop the appropriate management response as part of the size-up process by analyzing the current situation and expected fire weather.

Until the use of wildland fire to achieve resource management objectives is expressly approved in the park's Fire Management Plan, resource benefits will not be used as one of the considerations when determining the appropriate management response. The appropriate response will be determined after evaluating factors such as firefighter and public safety, values to be protected, estimated cost of suppression, external concerns, and land use.

9.3 Firefighter Safety

The 1995 Federal Wildland Fire Management Policy mandates that "public and firefighter safety is the first priority in every fire management activity." This policy must be brought to the forefront during all fire management operations and continuously addressed.

The safety of Service employees and cooperators involved in fire management activities is of primary concern. Only trained and qualified employees will be assigned to fire management duties. All fire management personnel will be issued personal protective equipment and will be trained in its proper use. No Service employee, contractor, or cooperator will be purposely exposed to life threatening conditions or situations except when necessary to save the life of another person.

The primary threat to firefighter safety is from fast moving wildfires driven by the wind or effected by steep terrain that can quickly over take and trap firefighters. It is important that fire fighters practice LCES (Lookouts, Communications, Escape Routes, and Safety Zones) at all times! Spot weather forecasts should be requested early-on during initial attack to gain insight into the possibility of shifting winds from approaching fronts, and other weather related phenomena.

In addition to the general hazards noted above, the following threats specific to the park have been identified.

- Slope reversal
- Rolling rocks and burning materials
- Snags and dead trees with butt rot
- Heavy concentrations of fuels that can block escape routes
- Steep/sheer cliffs
- Loose rock which can contribute to poor footing
- Narrow roads with sharp curves and blind corners
- Stinging insects and snakes
- Cave Openings and Sinkholes
- Abandoned water wells located at old home sites

Smoke from wildfires and prescribed fires is a recognized health concern for firefighters. Prescribed burn bosses and wildfire incident commanders must plan to minimize exposure to heavy smoke to 1 hour or less, at which time the firefighter should be rotated to a smoke free area (USDA Forest Service, Missoula Technology and Development Center).

9.4 Range of Potential Fire Behavior

Fire behavior in and adjacent to the park can range from fast moving surface fires or crown fires on southerly facing steep slopes to creeping duff fires in sheltered areas. For a more detailed discussion refer to the fire behavior descriptions in Section 6.3 Fire Seasons, Fuel Characteristics, and Fire Behavior.

9.5 Preparedness Actions

A. Wildland Fire Prevention and Prescribed Fire Education

Fire prevention includes all activities designed to reduce the number of human-caused wildfires that occur in the park. See Appendix 7 for the complete Fire Prevention Analysis and Fire Prevention Plan. In summary, the objective of the program will be to minimize preventable fires. The following actions will be taken to achieve this objective:

- Aggressively investigate all wildland fires
- Conduct prevention patrols during periods of very high fire danger

- Conduct prevention patrols during the fall when arson fires are most common
- Post appropriate signs during periods of high fire danger
- Participate in fire prevention and safety programs at public schools
- Issue press releases and distribute materials at state and local municipal levels plus the park visitor center and concessions facilities informing the public about the benefits of prescribed fire as opposed to the adverse impacts of wildfire
- Reduce fuels in visitor use developed areas, such as campgrounds, to reduce the likelihood of wildfire.

B. Annual Training

All persons involved in fire management activities are required to participate in 8 hours of fire management related refresher training annually in order to be qualified for fire management activities in that calendar year. Refresher training will concentrate on local conditions and factors, the Standard Fire Orders, LCES, 18 Situations, and Common Dominators. NWCG courses such as *Standards for Survival*, *Lessons Learned*, *Look Up, Look Down, Look Around*, and others meet the firefighter safety-training requirement. Efforts should be made to vary the training and use all or portions of other NWCG courses to cover the required topics. Fire shelter use and deployment, under adverse conditions, if possible, must be included as part of the annual refresher. The training can be given in an eight-hour block or presented in increments. Once completed, the training should be documented in SACS for each firefighter.

Individual development plans should be created for each firefighter. There is a need to develop ICT4's and RXB2's to adequately manage the fire program at the Park (See Section 8.2). Emphasis should be placed on sending interested personnel to the appropriate training and details, including the Prescribed Fire Training center in Tallahassee, and to arrange for outside evaluators to assess progress towards task book completion in order to gain qualified staff members.

FIREPRO funds are available to cover the cost of 100 and 200 level courses sponsored by the park and for a limited number of courses held outside the area. In order to participate, firefighters must submit requests for specific training courses to the Park Fire Coordinator for approval. Firefighters receiving approval to attend training outside the area are provided the FIREPRO account number. Travel documents are prepared and the appropriate personnel make arrangements.

C. Annual Preparedness Activities

As stated in NPS policy, preparedness is the foundation of an effective fire management program. Thorough planning will enable managers too easily and efficiently meet other fire management objectives. Preparedness includes activities conducted before fire occurrence to ensure the ability of the Park fire management organization to initiate effective action.

The following measures will be taken to ensure that all aspects of preparedness are addressed:

January: By the end of this month, all trained fire fighting personnel will submit updated information to the Fire Management Officer. This includes a new physical fitness score (if needed for that position), previous years fire experience, requested trainee assignments for the current calendar year, and requested training for the next fiscal year. Annual refresher training will take place. Plans for public information and education will be updated.

February: By the middle of this month, the Fire Management Officer will issue individuals their revised Incident Qualifications Cards. By the end of the month, sooner if dry conditions exist, the Fire Management Officer and Supervisory Park Ranger will conduct a readiness review to insure that all supplies, equipment, and engines are ready for use. All fire-qualified personnel will insure that personal protective equipment, and personal supplies are ready. They will correct any deficiencies. Public information and education plans to be implemented.

February–April: Spring fire season: Maintain a state of readiness as per Preparedness Staffing Classes in Appendix 8. With information received from Division Chiefs and supervisor, the FMO will complete a training needs analysis. The FMO will attend the annual meeting of the Kentucky Interagency Cooperators to discuss training needs and to discuss operating procedures and concerns.

May–June: Caches are restocked. The FMO holds spring fire season critique with the Chief Ranger and Supervisory Park Ranger (Operations) (others may be asked to attend).

July–August: Maintain and increase park employee skills through interagency wildland fire assignments. If needed, basic fire suppression courses will be taught.

September: The same preparations that were made in February must be made again to ensure preparedness for the fall fire season.

October–mid-December: Fall fire season. Maintain a state of readiness as per Staffing Classes.

D. Step-up Plan

Preparedness activities through out the year are based on the National Fire Danger Rating System (NFDRS). Fire days are broadly divided into five staffing classes according to the expected fire behavior as indicated by the Burning Index (BI). The BI integrates the effects of weather, fuels, and topography to estimate potential fire behavior and the corresponding amount of effort required to contain a fire. The staffing classes relate to the expected severity of fire conditions. Preparedness actions are those actions taken to provide extra protection during periods extreme or unusual fire danger, and, using WIMS, are based on the actual fire weather recorded on that day for all staffing classes.

Emergency funds are available for use when Staffing Classes IV or V are present. The funds can be used for hiring emergency temporary firefighters, placing existing staff on extended tours-of-duty, pre-positioning resources, increasing or initiating special detection operations, and leasing initial attack aircraft. All of these actions are aimed at ensuring prompt responses should fires occur.

The authority to spend emergency preparedness funds is tied to the BI. When a value equal to or greater than the 90th percentile (BI) is reached, funds can be expended as outlined in the approved Step-up Plan. A copy of the park's Step-up Plan may be found in Appendix 6.

The Kentucky Interagency Coordinating Center publishes a standardized chart of staffing classes which all agencies in the zone have agreed to use (see Table 5). NFDRS Fuel Model E (Hardwood Litter-Fall) has been selected as the most representative fuel type for the periods of highest fire danger which have been defined as March 1 to May 15 and October 1 to December 15.

E. Pre-attack Plan

Due to the scope of the fire program at Mammoth Cave, a formal pre-attack plan has been prepared (see Appendix 9). The park plan addresses the elements outlined in Chapter 7, of Reference Manual 18.

F. Detection

During periods of high fire danger, the Park conducts fire prevention patrols. All fires observed by park employees are reported to the Ranger Division. Fires that are reported by park visitors or local residents are usually reported to the Edmonson County 911 Dispatch. Edmonson Coun-

Table 7. Kentucky Interagency Coordination Center Staffing Classes

Burning Index	Ignition Component				
	0-20	21-45	46-65	66-80	81-100
0-7	L	L	L	M	M
8-15	L	M	M	M	H
16-18	M	M	H	H	V
19-22	M	M	H	H	V
23-25	M	M	H	H	V
26-29	M	M	H	H	V
30-32	M	H	V	V	E
33-35	M	H	V	V	E
36-42	H	V	V	E	E
43-50	H	V	V	E	E

L = Low, Class I Day
M = Moderate, Class II Day
H = High, Class III Day
V = Very High, Class IV Day
E = Extreme, Class V Day

ty Dispatchers contact the Park if the reported fire appears to be on Service lands. The County has an employee contact list, which makes contact easily. Another avenue for reporting fires is via the Parkwatch program in which people are encouraged to report any suspicious activity.

The Kentucky Division of Forestry provides aerial detection for the Central District beginning on Class 3-5 days and on Class 2 days at their discretion. The plane makes two circuits of the district during the course of the day. Rangers monitor the Division's radio frequency and fires are reported to the park through the district office.

9.6 Mobilization

A. In-Park Assignments

The Fire Management Officer maintains a list of firefighters available to respond to wildland fires reported in or threatening the park. When a report of a fire is received, the Fire Management Officer designates an Incident Commander, and contact firefighters based on type and number needed. The Fire Management Officer will contact employees from all divisions through their supervisor for in-park dispatches. Mutual Aid responses from the State of Kentucky for fires occurring near or adjacent to the park boundary are handled in the same manner. A copy of the Park Mobilization Plan can be found in Appendix 10.

B. Initial Attack

When multiple fires are reported, the following will be used to set priorities:

- Threats to cultural and historic sites
- Threats to critical habitat to rare, threatened, and endangered species
- Threats to sensitive karst features
- Threats to private property
- Threats to park developments

Criteria for appropriate initial attack response that is consistent with Park goals and objectives:

- Public and firefighter safety
- Protection of cultural, historic, and natural resources
- Protection and improvements and private property
- Minimum fireline construction
- Availability of suppression resources and response times
- Fire behavior based on fuels, weather, and topography
- Minimizing the use of mechanized equipment and aircraft except where deemed necessary to meet criteria listed above.

A confinement strategy may be used for initial attack strategy as long as it is not being used solely to meet resource management objectives. Resource benefits may be a by-product, but the strategy must be based on the criteria previously listed. A confinement strategy may also be selected in the WFSA process when the initial attack action failed to contain a wildland fire. Typical response times to wildland fires may vary depending on staffing and individual personnel work assignments. An effort will be made to respond to a wildland fire within 30 minutes of receiving a report.

C. Extended Attack

Extended attack occurs when a fire has not been contained or controlled by the initial attack forces and continues either until transition to a higher level incident management team is completed or until the fire has been contained and or controlled. Whenever it appears a fire will escape initial attack efforts, leave Service lands, or when fire complexity exceeds the capabilities of command or operations, the IC will take appropriate, proactive actions to ensure additional resources are ordered. Extended attack action requires that a Wildland Fire Situation Analysis (WFSA) be completed to re-evaluate the suppression strategies.

The WFSA is a checklist intended to guide the Agency Administrator in assessing the current situation, developing alternatives, evaluating those alternatives, and deciding on a course of action. The situation is reviewed daily to determine the effectiveness of the strategy chosen. See Appendix 11 for an example of a WFSA checklist.

In the event an Incident Commander or Incident Management Team is ordered, the transfer of responsibility for suppression actions on the fire will be documented through a Limited Delegation of Authority signed by the Superintendent or designated Acting. A draft copy is located in Appendix 12.

D. Out of Area Assignments

The Fire Management Officer is contacted by the Kentucky Interagency Coordination Center with the Resource Order information. The Fire Management Officer maintains an availability list during periods of high fire danger in the zone or nation. The Fire Management Officer contacts the

appropriate Division Chief to gain permission to commit the firefighter if the firefighter or resource requested is available. Once the Division Chief grants permission, the Superintendent will approve or disapprove. The requested resource is contacted, and if available, committed to the assignment. Normally there is a 1-hour "Fill or Kill" time specified by the Kentucky Interagency Coordination Center. The park usually commits 1-3 firefighters to the Lexington (KY) Module, and individual overhead orders are filled as needed. These resources are pre-identified but the request is handled as outlined above.

9.7 Minimum Impact Suppression Tactics

Fire management activities within the Park will be carried out in a manner that minimizes impacts to the Park's natural and cultural resources, while maintaining the safety of firefighters, the public, and other personnel. Minimum Impact Suppression Tactics to be used when suppressing fires in the Park include:

- The approval of the Superintendent is needed for off-road use of vehicles and the use of plows and other mechanized equipment, unless significant values to be protected are threatened. When mechanized equipment is used for line construction, a resource advisor from the Division of Science and Resource Management will be assigned, if possible, to clear the route ahead of the piece of equipment.
- *Minimum use of retardant. Any use of retardant will be reviewed by an assigned resource advisor and approved by the Superintendent.*
- Use of existing natural or manmade barriers whenever possible.
- Use leaf blowers and wet-lines wherever possible.
- Cold-trail the fire edge when practical.
- Branches and other debris from line construction will be scattered in accordance with guidelines contained in the Fireline Handbook (PMS 410-1)
- Use mop-up kits and other low pressure nozzles setting to prevent erosion.
- Minimize the falling of trees. Snags near the fireline will be removed only if the present a hazard to firefighters or constitute a threat to the fireline integrity. Lower branches on living trees will be pruned to remove ladder fuels as opposed to falling the tree.
- Water bars will be placed on steep slopes.

9.8 Rehabilitation

All rehabilitation actions will be in accordance with Service Policy. After the fire is declared out, all flagging, litter, and trash associated with the suppression operations will be removed. Firelines will be rehabbed and erosion control devices installed as necessary. Stumps will be flush cut and covered with soil. Brush will scattered and, on slopes, boles of fallen trees will be placed parallel to the hill to form erosion control devices. Plow furrows will be rehabilitated by rolling the materials back into the furrow. Plow furrows will be rehabilitated only after a professional archeologist has completed a survey and documentation of any archeological resources found. Public use trails will be patrolled and measures taken to insure public safety.

The severity of the burn and the resulting impacts may dictate the need to re-seed or reestablish native plant species. Re-seeding during rehabilitation of wildland fires located near either the Green or Nolin Rivers will be given additional priority because of the presence of six or more federally protected mussel species. An adequate buffer area at least 50 meters wide will be established. In these instances a formal rehabilitation plan will be prepared and approved in accordance with Service policy.

Service policy states that only damage to improvements caused by suppression efforts and repairs required to protect park resources from imminent damage can be repaired using fire funds. Service fire funds cannot be used to repair damage caused by the fire itself (i.e. burnt fence lines, bridges, structures, etc.) These funds must come from other sources.

9.9 Records and Reports

A. Individual Fire Report (DI-1202)

The Individual Fire Report (Commonly referred to as a 1202) is the primary means of documenting fire management activities for the Department of the Interior. A 1202 is to be used to document wildland fires, including natural outs, support actions, false alarms, and prescribed burns.

The Initial and/or Extended Attack Incident Commander is responsible for completing the 1202 as well as Crew Time Reports for personnel assigned to the incident, requisitions for items expended on the incident, Compensation and Claims for injury forms, and other documents relating to the incident. The person completing the 1202 will get a fire number from the FMO and an account number from the regional FMO.

A completed 1202 actually forms a package that may include the following:

- Any written documents signed by the Superintendent.
- A copy of the WFSA
- The original copy of the Resource Order Form(s)
- Copies of Crew Time Reports, Individual Firefighter Time Reports
- Listing of firefighters, including positions held
- Copies of requisitions
- Situation maps that indicate the daily fire advance, weather data, etc.
- Accident Reports
- Press clippings
- Rehabilitation Plan

The completed package is submitted, as a draft document, to the FMO who will review the report for completeness. Once the review has been completed, the data is entered into the SACS database within 10 days of the fire being declared out and the package filed in the FMO's office for permanent record keeping.

B. Resource Order Form (NFES 1407)

All requests for outside assistance will be documented on a Resource Order Form (NFES 1407). The order form is, in essence, an obligating procurement document. When incoming orders are received for park resources, the coordination center should fax a copy of the Resource Order for park files.

C. Daily Situation Report

Daily Situation Reports should be submitted on those days when the Park moves into Staffing Classes 4 and 5, or when a fire has occurred or is on going. The FMO is responsible for preparing the report and entering it into the Shared Applications Computer System (SACS) by 0930 Hrs. An ICS 209 form is completed and forwarded to KICC when fires exceed 100 acres for timber or brush or 400 acres for grass fuels.

D. Fire Experience and Qualifications

The Shared Applications Computer System (SACS) at NIFC is the central repository for all-individual firefighter experience, fitness, and training records. The FMO is responsible for entering all training and experience into the system and ensuring the information is up to date. Before the Spring Fire Season, each firefighter should be given the opportunity to check and validate their records and make any corrections, if necessary. This can be done as part of the annual IDP process.

E. Year-end Accomplishment Report

The FMO will complete and submit the year-end accomplishment reports in time to meet Regional and National deadlines.

10.1 Scope of the Prescribed Fire Program

There are two components within the prescribed fire program: ecological restoration and hazard fuel reduction. Due to inherent risks, hazard fuels will generally be reduced mechanically. Therefore, most of the prescribed fire program will be directed toward correcting distortions to natural biotic communities caused by fire suppression over many decades. This extends into the realm of threatened and endangered species management such as with Eggert's Sunflower, and where applicable, to control of invasive alien species which will be briefly addressed below.

The broad spectrum of habitat types from dry to wet on different types of substrates are summarized in Table 1 and Figure 2. Based upon this analysis, approximately three fourths of the park will carry fire during dry spells in spring and fall. Given that this fraction of the park is nearly 40,000 acres in areal extent, it is safe to conclude that fire will be restored very slowly across the landscape over the coming decades. This is not a problem for two reasons: first, our prescribed fire program must be adaptive based upon fire effects monitoring data plus research, and second, much of this "eligible" acreage was farmed prior to park establishment, and is today in dense, sucessional stands of cedar and pine. These coniferous forests (see Figure 3) probably need more time before they can benefit from fire. The sites designated for prescribed fire (see Figure 4 and Appendix 4) were largely selected from among areas with minimal historic disturbance, and maximum potential for restoration of ecological integrity and biotic diversity.

Cedar-Oak Glades

In the driest limestone habitat types (calcareous xeric and sub-xeric), especially on south to west facing slopes, cedar-oak glades prevail. These are sites where eastern red cedar is not suces-

sional, and where the inherent dryness of the site is an important factor in limiting growth of deciduous trees other than drought tolerant species such as chinkapin oak and blue ash. Based upon field observation of scars, fire is also a factor in limiting the invasion of more mesic species. However, given the vulnerability of eastern red cedar, fire intensity must be typically low, and the ability of cedars to grow right out of exposed limestone benches puts some distance between them and the meager fuel available.

Ridgetop Pine-Oak Stands

Located on the dry edges of sandstone cliffs facing south to west, acid xeric habitats support nearly pure but narrow stands of virginia pine and chestnut oak. Analogous to the cedar-oak glades, these sites are where Virginia pine is not successional. Droughty conditions are clearly a factor in the maintenance of these stands, but the role of fire is not known. Observations in the field have failed to detect fire scars on either pines or oaks, so until the role of fire is better understood, these stands will remain low on the list of priorities.

Oak-Hickory Forest/Savanna

On broad uplands in the park separated by large karst valleys south of Green River, oak-hickory forest covers relatively large areas of acid mesic-subxeric and calcareous sub-xeric habitat types which have been minimally disturbed. North of the river, sandstone capped uplands with similar habitats supporting oak-hickory forest are divided by narrower drainage channels. It is possible that portions of these uplands were oak savannas before settlement, especially areas adjacent to southerly slopes where fuels are more frequently combustible. For now, the goal for prescribed fire in oak-hickory forest is to reduce the invasion of fire intolerant species such as beech and maple.

Karst Valley Forest/Savanna/Prairie

Presettlement vegetation types in karst valleys south of Green River are unknown, and most of these large expanses of calcareous sub-xeric habitat were farmed before park establishment. Research on stable isotopes of carbon and oxygen (Doral et. al., 1998) are needed to determine presettlement vegetation patterns back through time. Until these data are acquired, the goal for prescribed fire in karst valleys will be limited to maintenance of isolated prairie patches, and small-scale experiments in successional stands of cedar/pine.

Mesic Slope and Floodplain Forests

Moist ravines connected with the major river valleys support beech and maple in largely calcareous mesic habitats. On the floodplain alluvium, boxelder, sycamore, and river birch complement beech and maple. These habitats receive limited sunlight to dry fuels, and are watered by runoff in addition to their own catchment. Therefore, the frequency of presettlement fire must have been very low. The same can be said for the supra-mesic habitats, and there are no plans to introduce fire in these areas. In some instances, portions of these very moist habitat types will be included within a prescribed fire unit to make the fire line safer and easier to manage, but this fire-intolerant vegetation will not be forced to burn.

The types of native vegetation summarized above are being impacted to varying degrees by invasive alien species. Some of these invaders can potentially be managed with fire and include:

Alliaria petiolata (Garlic mustard) – A biennial herb that begins vegetative growth in early spring and blooms from April through June. The species reproduces readily from seed, can grow in dense shade, and is rapidly invasive in floodplain forests, savannas and roadsides. Garlic mustard is widespread in the Midwest and Northeast, and it is spreading within the park. Fire has been used successfully to control this species in the Midwest. Fall or early spring burns are best, with treatments repeated for several years.

Lonicera japonica (Japanese honeysuckle) – An aggressive colonizer of successional fields and disturbed areas such as roadsides; it can also become established in mature forests. The semi-evergreen vine climbs and drapes over native vegetation, and is common in the park. It spreads from seed and vegetative runners. In fire-adapted communities, prescribed burns during the spring greatly reduce the vine's coverage and crown volume. Repeated fires reduce honeysuckle volume by up to 50 percent. Fire may also be used in combination with applications of approved herbicides during the dormant season.

Microsteqium vimineum (Japanese grass) – A low, spreading annual grass which is widespread in the park and dominates many shaded, dis-

turbed sites. It is prolific in the production of seeds, which can remain viable in the soil for over 5 years. Fire could be useful in reducing this species when timed correctly to prevent seed development.

10.2 Prescribed Fire Planning

The following guidelines will be used to develop plan annual prescribed burning plans:

- The Division of Science and Resource Management will develop the annual burn program. They will identify areas to be treated, develop burn objectives, write or provide input into burn plans, and identify monitoring and research projects.
- The Prescribed Fire Committee (Section 8.1) will meet at least annually to review the fire management program. The purpose of this meeting is to review proposed burns and schedule them if possible.
- Once approved, the plans will be submitted as part of the FIREPRO budgeting process for consideration for funding. The Division of Science and Resource Management may also request funding from other sources for monitoring and research projects.
- The Chief of Ranger Activities will implement approved projects, with the assistance of other Division Chiefs.

A five-year plan listing the highest priority Prescribed Fire Areas has been developed and can be found in Appendix 13. This is an attempt to organize our efforts, but is subject to change as needed to accommodate new information. On this basis, the Division of Science and Resource Management will identify additional areas for treatment so that the park's resources are managed to the best degree possible. Treatment can include the use of mechanical and chemical means, either independently or in combination with prescribed burning to achieve the stated objectives. Scheduling of the PFAs will depend on environmental conditions, as it is important that fuels and weather parameters meet preconditions indicated in burn plans. It is also important to note that while Prescribed Fire Area boundaries have been mapped in the GIS, the Burn Boss has considerable flexibility in placement of fire lines. Safety of fire management personnel and successful containment of prescribed fire form the basis for this needed flexibility. This does not mean that vegetation community types not adapted to fire (beech-maple in mesic hollows for example) will be made to burn because they are within the fire line. In most cases, the fire will be allowed to extend into these community types to the degree it would naturally spread from the community type for which fire has been prescribed.

10.3 Personnel Requirements

The park has a large enough staff to meet the staffing needs necessary to implement the plan; however, the staff lacks the training and experience to provide key positions to conduct the program "in house". Table 3, Minimum Staffing Targets, contains a listing of the positions required to be fully self-sufficient.) Until park personnel can become trained and qualified, the park must rely on outside staffing. Possible sources include; the Daniel Boone National Forest, Asheville Hotshots, Great Smoky Mountains National Park, the Great Smoky Mountain Fire Use Module and Fire Effects Team, and other Service and Cooperator personnel from the Southeast who are experienced in the particular fuel type(s). The resources will be ordered based on the complexity of the burn as determined by the Complexity Analysis completed for each prescribed fire.

10.4 Fire Behavior and Fire Effects Monitoring

A fire behavior monitoring program will be developed as part of the fire management program (to be included as Appendix 14). The following guidelines will use are the required minimum documentation set forth in the Southeast Region Wildland Monitoring Guide:

- Map of burned area.
- Preceding and current drought indicator readings (KBDI).
- Fire weather conditions.
- Maximum temperature during burning period(s).
- Average wind speed and direction during burning period(s).
- Minimum relative humidity during burning period(s).
- State of the weather (cloud cover, type of rain, snow, and lightning activity).
- Any weather condition that had a significant impact on the fire (thunderstorm, frontal passage).

A. Fire activity narrative:

This section may be highly subjective. As many of the items listed below should be addressed as well as any items that are determined appropriate.

- Fuel/vegetation type

- How fire behavior affected suppression strategy. Note any extreme fire behavior (torching, crowning, fire whirls).
- What suppression strategy was used (confine, contain, control)?
- Type of fire behavior (smoldering, creeping, running, crowning).
- Photo documentation
- Estimated or exact days since last rainfall and amount. Specify if estimated or actual amount.
- Estimated or measured rates of spread (chains per hour) and flame length.
- Estimated or calculated slope.
- How did smoke disperse? Did columns develop? Any traffic problems?

B. Fire Effects Narrative:

This section is also highly subjective. As many of the items listed below should be addressed as well as any items that are determined appropriate. The degree of accuracy should be specified for all values recorded.

- Were tree canopies partially or completely consumed (scorched)?
- Was the duff or soil burning after fire passed?
- What is the potential for serious erosion, and is a reseeding and/or restocking plan needed?
- What are the effects on wildlife?
- Was there a lot of unburned area within the fire perimeter?
- How high tree bark blackened (charred) by the fire?
- Is photo documentation required?
- Were any rare, threatened, or endangered species affected? (If yes, what were the specific effects?)
- Is the burned area near or affect wetlands, floodplains, or mussel habitat?
- Did suppression tactics such as handlines or plowlines significantly affect any resources?
- Were any cultural resources impacted?
- What affect, if any did the fire have on visitor use?

A fire effects monitoring program will be included as part of the prescribed fire program. Long-term monitoring will include the installation of permanent plots in representative fuel types to determine the effects of prescribed fire. All plots will be sampled before treatment and will be sampled after the treatment to gather data for both short-term and long-term effects. The program will ascertain if the quantifiable Prescribed Fire Area objectives identified in the individual burn plans have been achieved, and if the desired long-term ecological changes are occurring. Monitoring results will be used to validate the program, adjust prescriptions, and identify new units suitable for similar treatment. See the Monitoring Section (13) for further discussion.

10.5 Documentation and Reporting Requirements

As the prescribed fires are conducted, they will be reported in the Shared Applications Computer System (SACS). The Burn Boss is responsible for completing the Individual Fire Report DI-1202 and submitting it to the Fire Management Officer within three (3) days for entry into SACS. The Burn Boss will also update the report, as required, and submit the additional documentation to the Fire Program Manager who will enter it into the system. The Prescribed Fire Monitor will complete the forms specified in the Monitoring Handbook. The Burn Boss will also be responsible for the completion of fire time reports and completing necessary forms to replace expended supplies and document other charges to the project.

10.6 Reviews

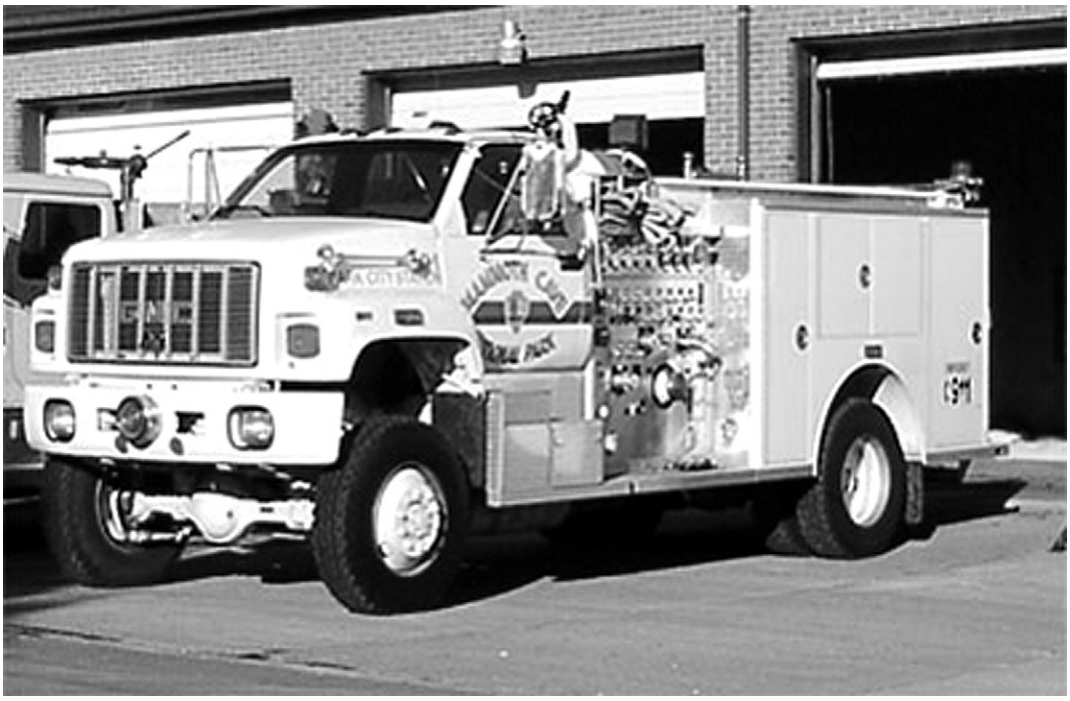
All prescribed fires conducted in the park will receive at a minimum a review by those involved to evaluate operational aspects associated with the incident. The Incident Commander and the Chief Ranger and/or the Fire Management Officer will conduct the review. The purpose of the review is to recognize and document actions that were successful and identify and correct actions that did not contribute to the successful conclusion of the incident or compromised firefighter safety. These reviews will be conducted according guidance provided in Chapter 13 of RM-18.

Under the provisions of the Clean Air Act as amended in 1977 and 1990, Mammoth Cave National Park is classified as a mandatory Federal Class I Area. The fire management program will comply with all requirements of the Clean Air Act, 42 U.S.C. §7418. The State of Kentucky exempts from the provision of KRS 77.155 the "smoke from fires set by or permitted by any public officer if such fire is … for the purpose of weed abatement, the prevention of a fire or health hazard…." The Kentucky Division of Forestry and the Kentucky Interagency Coordination Center will be notified before any burn of the location and expected duration of the

proposed burn. Detailed smoke management actions will be made part of each prescribed burn plan. The detailed plan will include provisions to identify the smoke hazards associated with all fire management and assess the possibility of smoke affecting federal protected species. Provisions for monitoring smoke hazards will be included. Smoke trajectory maps will be developed and sensitive targets identified. Mitigation measures will be defined in the plan and arrangements made before ignition to insure designated resources are available if needed to implement the mitigation measures. Smoke management will also entail the evaluation of current air quality parameters and the effect of fire on air quality within and outside the park. Emissions from wildland and prescribed fire can be a significant source of air pollution. Smoke particles are in the size range (<2.5 micrometers) that also plays a significant role in visibility impairment.

Emissions from wildland and prescribed fire include carbon dioxide, carbon monoxide, and other gases in addition to water vapor and particulate matter, which can combine to form smog and fog. Emissions from wildland fire are not controllable, while emissions from prescribed fire can be predicted. By adjusting ignitions for good dispersal and combustion, public health and nuisance factors of generating emissions can be reduced. Smoke screening, i.e., the identification of potential receivers of smoke from wildland or prescribed fires, was integrated with the identification of fire management units

Mammoth Cave NP currently monitors ozone, sulfur dioxide (SO_2), carbon monoxide (CO), nitric oxide (NO), total reacted nitrogen (NO_y),



11.0 Air Quality / Smoke Management

particulate matter ($PM_{2.5}$ and PM_{10}), visibility (aerosol and optical), wet deposition, and volatile organic compounds (VOC). The EPA designated Edmonson County, Kentucky, as a non-attainment area for ozone in 1990 after recording six violations of the 1-hour ozone National Ambient Air Quality Standard (NAAQS) from 1987 to 1989. Edmonson County, Kentucky, was re-designated as attaining the ozone NAAQS in 1995, following six years of measurements below the ozone NAAQS.

The worst air quality days occur in winter because of low boundary layer conditions, and summer due to stagnant air masses. Wildland and prescribed fires in these seasons would produce the most detrimental emissions impacts on air quality and human health. Prescribed fires will reduce the amount of fuel that would be consumed in wildland fire, and reduce the negative effects by including smoke management in the prescribed burn plan. Air quality modeling suggests that using prescribed fire to minimize wildfires can result in a net reduction in fine particle ($PM_{2.5}$) emissions.

To protect public and firefighter health and safety, the park will:

- Monitor visibility on the fireline for all prescribed fire or wildland fire.
- Limit exposure by burn crew members to <2 hours when visibility is less than 100 ft.
- Post signs in roads when visibility is impaired by smoke from prescribed fire.
- Monitor particulates during prescribed fires lasting longer than 24 hours and develop a smoke management plan with state and regional air quality regulators.
- Monitor crew exposure to carbon monoxide.
- Calculate total smoke production from fuel measurements and post-fire fuel consumption measurements.
- Generally conduct large prescribed burns only when mixing height is forecast to be greater than 1500 feet above burn elevation.
- Conduct prescribed fire under favorable transport wind conditions.
- To the degree possible, develop a site specific emissions dispersal index using available programs for modeling smoke behavior.
- To the degree possible, develop a site specific model comparing emissions from prescribed fire with emissions from wildland fire.
- Review complaints of smoke impacts from prescribed fire.
- Apply ignition techniques that minimize the amount of smoke produced by a prescribed burn.

Given that fire suppression has been very successful at Mammoth Cave National Park, the frequency of ignitions has been low, and there has been little focus on fire research. Resource Management Plan project statements with fire research components include:

MACA-N-080 "Role/History of Fire and Development of a Fire Management Plan" calls for dendrochronological study of standing dead or fallen trees, sampling of soil for charcoal and biogenic opal. Dendrochronology will yield data on recent fire frequency and intensity, charcoal will be carbon-14 dated for a prehistoric timeline, and biogenic opal can be used to identify grasses which formerly grew at a given location.

MACA-N-106 "Paleo-Climate and Vegetation History" outlines a program of study on carbon and oxygen isotopes in stalagmites from cave passages underlying a spectrum of habitat types that would have supported vegetation ranging from prairie to closed canopy forest. Carbon isotopes will yield information on dominant vegetation types, and oxygen isotopes will provide information on average temperatures.

Anticipated projects include:

1. "Refine Vegetation Habitat Model" which will describe initial work on the GIS-based habitat classification used in this Fire Management Plan, and how to improve it via a higher resolution digital elevation model coupled with field measurements of slope/aspect near vegetation community boundaries. Utility of habitat modeling includes prediction of fire-dependent vegetation community polygons, and interpretation of current vegetation patterns.

2. “Refine Digital Vegetation Community Map” which will describe initial work on the digital vegetation map used in this Fire Management Plan, and prescribe acquisition of Ikonos (4 meter resolution) and Landsat 7 (30 meter resolution) multi-spectral satellite imagery. The greater spectral resolution of the vastly cheaper Landsat dataset will be used to better characterize vegetation in the finer Ikonos images. The resulting improvements over the current digital vegetation map (based on older Landsat data) will support higher-resolution fuel modeling park-wide.

Beyond these projects, the Prescribed Fire Areas (PFAs) displayed in Figure 4 are designed as

12.0 Fire Research

research units. Each PFA is included on habitat and vegetation maps (Figures 2 and 3 respectively), and each has a quantitative GIS-based data sheet detailing habitat types, disturbance history, vegetation types, previous fires, and other relevant information useful in fire research. Some PFAs, such as S2A&B and S6A&B are designed as matched pairs on either side of Green River to test for fire-break effect of the river (assuming more frequent prehistoric ignitions on the south side). Botanical responses to prescribed fire in these PFAs could shed light on this question. Similarly, PFAs S3A and S10C have equivalent and complex habitats, and both are near Green River but on opposite shores.

Recording information on behavior during a fire, and on effects post-burn is a crucial part of an adaptive fire management strategy (see Fire Behavior and Fire Effects Monitoring in section 10.4 for further discussion on fire behavior monitoring). Such information improves our ability to predict fire behavior, which is important for both safety and ecological restoration reasons. As well, the closer systematic scrutiny demanded in collection of monitoring data helps to identify situations where research is needed. In 1992, the Western Region of the National Park Service published a Fire Monitoring Handbook that organized monitoring into four levels. This approach has since been adopted service-wide, and will be employed at Mammoth Cave National Park.

The park will develop short and long term monitoring programs to assess the effectiveness of fire management activities on cultural and natural resources (to be included as Appendix 14). The NPS Fire Monitoring Handbook protocols will be used to fulfill monitoring plan requirements, and a copy of the handbook is available at the Ranger Station and Resource Management Offices. The Science and Resources Management Division will work with the with the Regional FMO, Fire Ecologist, Prescribed Fire Specialist, and the Fire Effects Monitoring Team based at Great Smoky National Park to determine the appropriate monitoring techniques to be used in sampling the plots. The habitat types mapped in Section 3.3 and the vegetation types mapped in Section 3.4 formed the basis for selection of Prescribed Fire Areas, and therefore the sites to be monitored. For each Prescribed Fire Area, a Monitoring Type Description Sheet (FMH-4) will be completed, and an example is attached in Appendix 14.

All aspects of the fire management program will provide for public safety, and the incident will be managed so that the safety of firefighters, park and concessioner staff, neighbors and the visiting public are protected. The safety of all people in the area is the primary concern of the Incident Commander or Burn Boss.

The typical wildland fire in the Park is 10 acres or less. This makes it somewhat easy to monitor the entire perimeter of the fire to ensure the public is kept out of the immediate area and are far enough away that they will not hinder the suppression activities. Under no circumstances will anyone be permitted near a fire without the appropriate training and required personal pro-

13.0 Monitoring

tective equipment. Members of the press will be allowed in the vicinity of the fire if they are determined to meet the standards established for the Light fitness rating, wear personal protective equipment, including a fire shelter, and are accompanied by a trained, qualified firefighter who can assist them.

Large fires may dictate the need to close a portion of the Park to the visiting public. The Chief Ranger is responsible for enforcing the closure. Every effort will be made to inform backcountry hikers, campers, and the public of the situation and evacuate the area, if necessary. Signs will be posted at the trailhead warning hikers and backcountry users of the situation. When a fire threatens to escape the from the park or has the potential to do so, adjacent authorities and landowners will be given as much advanced notice as possible so that they may take appropriate action.

Mitigation measures will be outlined in each individual prescribed burn plan. Necessary action will be taken to insure public safety including contacting park neighbors, posting warning signs on roads, providing for pilot cars, closing of backcountry areas, posting signs at trailheads and at the Visitor Center warning hikers and backcountry users of the situation, and evacuating park neighbors who may be adversely affected by smoke. Park neighbors are to be given as much advanced notice to properly plan for the event.

An informed public is a vital component of the prescribed fire program. Areas that have been burned will present opportunities for the public to actually see the effects of fires, and offer staff members and opportunity to explain the

purpose of the burns to the public. There are several ways to convey this message to the public including interpretive folders such as *Wildland Fire in the National Park Service*, presentations to school children in the field or in the classroom, attendance at meetings, and through press releases. If the situation warrants and adequate supervision is available, the public may actually observe a prescribed burn as it is conducted. During the burn, the Burn Boss and PIO are responsible for dispersing information to the public; however, it is best to delegate this responsibility to the PIO whenever possible.

The visiting public and local population will be made aware of local conditions during periods of high fire danger. This can be accomplished primarily through signing and the issuance of press releases. Wildfires convey a different set of circumstances in that they are unplanned events that constitute emergencies. Public access must be managed. Any media access to wildland fires will comply with safety guidelines outlined above. During the fire, Incident Commander is responsible for dispersal of information to the press and the public. This activity may be delegated. Post-fire information will be issued in accordance with park public information guidelines keeping possible future FOIA requests in mind.

16.1 Archaeological and Historic Features

There are over 1,008 identified prehistoric and historic archeological sites in the park representing almost 10,000 years of human history. The historical resources of the park are extensive. There are 28 structures and one archeological site on the National Register of Historic places including churches cemeteries and buildings plus a train steam engine and combination car. Many of these features and resources are open sites, and many are associated with shelter caves. Fire effects on cultural resources have been well documented, and include the direct consequences of fire on materials such as wood and glass. The effects of fire management related actions such as fire line construction on resources could also be significant. These resources are widespread, and are mapped as a datalayer within the GIS. PFAs were designed to avoid cemeteries, archeological, and historical sites whenever possible (see Figure 6). Where avoidance was not possible, such as

open areas near historic structures or cemeteries, mowing and/or wetlines will be used to prevent fire from reaching sensitive resources.

16.2 Natural Resources

Most of the endangered species in the park are aquatic, and not likely to be affected by fire typical of Kentucky. However, when wildland fire produces potential for stream changes that could affect mussels, the park will develop an appropriate monitoring and rehabilitation plan to minimize the effects, if any.

Hibernating bats in caves are however vulnerable. Airflow in Kentucky caves is largely driven by the Chimney Effect, in which air is exchanged through entrances at different elevations. In winter, cave air rises out of upper entrances, creating a partial vacuum, which draws cold surface air into lower entrances (Jernigan, 1997). Some of these lower entrances in the park are habitat for hibernating Indiana and Gray Bats, which are federally listed as endangered (see Figure 6 for approximate locations). Therefore, prescribed burns will not be ignited if weather conditions would cause smoke to be inhaled into bat hibernacula. Prescribed fire will not be implemented in the fall before November 15th to avoid interfering with bat swarming behavior in cave entrances, and there will be no prescribed fires in the park after April 30th to avoid disturbing bats roosting in trees. The window for igniting prescribed fires is November 15th through April 30th annually.

The one park plant species listed as threatened, Eggert's Sunflower, has become imperiled partly due to fire suppression, and therefore will benefit from fire. Soil erosion could potentially

16.0 Protection of Sensitive Resources

affect aquatic and terrestrial species, but will be prevented by immediate site rehabilitation as discussed in Section 9.8. Fire related disturbance might enhance alien plant species. These will be detected in the monitoring effort and controlled through mechanical and/or chemical means, or possibly more prescribed fire.

17.1 Fire Reviews

All wildland and prescribed fires occurring in the park will receive at a minimum a review by those involved to evaluate operational aspects associated with the incident. The Incident Commander and the Chief Ranger and/or the Fire Management Officer will conduct the review. The purpose of the review is to recognize and document actions that were successful and identify and correct actions that did not contribute to the successful conclusion of the incident or compromised firefighter safety. These reviews will be conducted according guidance provided in Chapter 13 of RM-18. The Superintendent will conduct a closeout meeting with Incident Management Teams (IMT) to ensure a successful transition of the incident back to the park. Chapter 13, Exhibit 1 of RM-18 contains a sample closeout review with an IMT.

17.2 Plan Review

The Chief of Science and Resources Management will coordinate reviews of the plan. These will be conducted annually, and a formal fire management review will be conducted every five years. The FMO will handle operational sections, and the Park Ecologist will handle sections relevant to ecosystem management. The Superintendent must approve significant changes to the body of the plan. The only exceptions to this procedure will include grammatical corrections, minor procedural changes, deletions, corrections, and additions to the appendices. Copies of all changes will promptly be forwarded to the Regional Fire Management Officer. Changes requiring approval and concurrence will be submitted with a new cover sheet for signature and dates, which will replace the original cover sheet on receipt by the Superintendent.

Fire Management Plans from the parks listed below were consulted to provide guidance:

Colorado National Monument

Great Smoky Mountains National Park

Big South Fork National Recreation Area (Draft)

Kings Mountain National Military Park

Natchez Trace Parkway

The following individuals were consulted during the development of this plan:

17.0 Fire Reviews and Annual Plan Review

Jim Aldrich The Nature Conservancy

Joyce Bender Kentucky State Nature Preserves Commission

Jeff Bradybagh Zion National Park

Julian Campbell The Nature Conservancy

Bill Gabbert Wind Cave National Park

Bob Carson Mammoth Cave National Park

Dave Crary Cape Cod National Seashore

Robert Emmott Big South Fork National River and Recreation Area

Mark Evans Kentucky State Nature Preserves Commission

Ken Garvin National Park Service – Southeast Region

Frank Graham Big South Fork National River and Recreation Area

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Dan Mapstone Natchez Trace Parkway

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18.0 Consultation and Coordination

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